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APPLICATION OF CODING METHODS IN DEVELOPMENT OF SYMBOLOGY FOR A COMPUTER-GENERATED TOPOGRAPHIC DISPLAY FOR ARMY AVIATORS

SUBMITTED TO:

ADVANCED SYSTEMS DIVISION (DAVAA-F)
U.S. ARMY AVIONICS R&D ACTIVITY
FORT MONMOUTH, NEW JERSEY 07703

MARCH 1982

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This report presents the results of a literature review conducted to identify previous research that could provide guidelines during the initial design of a new symbol system for topographic and tactical data display. Methods of symbol design based on ten dimensions of visual coding--shape, alphanumeric, size, numerosity, inclination, brightness, color, flash rate, stereo depth, and apparent movement--are identified and evaluated. The evaluation of alternative coding methods is based on three design-oriented criteria: amount of information

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conveyed, types of data coded, and aid to operator visual search. These criteria are considered in the review of research investigating both unidimensional and more complex multidimensional symbol systems. A model is presented which identifies the relationships between many factors and symbology system characteristics that ultimately affect the design of symbol systems.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

SECTION

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF TABLES

SECTION 1
INTRODUCTION

Until recently, most symbology systems have evolved over long periods of time. The symbology used on topographic maps, for example, has been evolving for centuries. In contrast, technological advances in electronic information display capabilities have required that new symbol systems be developed very rapidly. The system designer must be prepared to adapt existing symbols when possible, create new symbols when necessary, and ensure that all of the desired information is presented in the most legible and comprehensible manner possible. When faced with such tasks, designers of symbology may find that available engineering and human factors handbooks do not adequately guide the initial phases of design prior to actual test and evaluation. This report presents the results of an extensive literature review performed to identify the critical issues in the initial phases of the development of symbology for topographic and tactical data displays. This project was undertaken as partial fulfillment of the requirements of Contract No. DAAK80-81-C-0089, issued by the U.S. Army Communications-Electronics Command (CECOM), in support of the Avionics R&D Activity (AVRADA) at Fort Monmouth, New Jersey.

CGTD SYMBOLOGY

A computer-generated topographic display (CGTD) is currently under development by AVRADA. The CGTD will provide comprehensive cartographic support, displaying topographic data in the scales required for nap-of-the-earth (NOE) flight. In addition, the CGTD offers a truly interactive system, permitting the user to control the content of the displayed information and to employ powerful computational capabilities such as construction of shaded "relief maps," presentation of perspective views of terrain, and indication of areas masked from radar observation. The CGTD will be valuable for mission-planning, navigation, and tactical decision-making activities. Because the CGTD introduces new kinds of information, and because it uses a pixel-matrix CRT display (rather than ink on paper), a new symbology system is required for use with this device.

The six interrelated tasks that lead to the specification of alternative CGTD symbology systems and symbol sets are depicted in Figure 1. This report presents

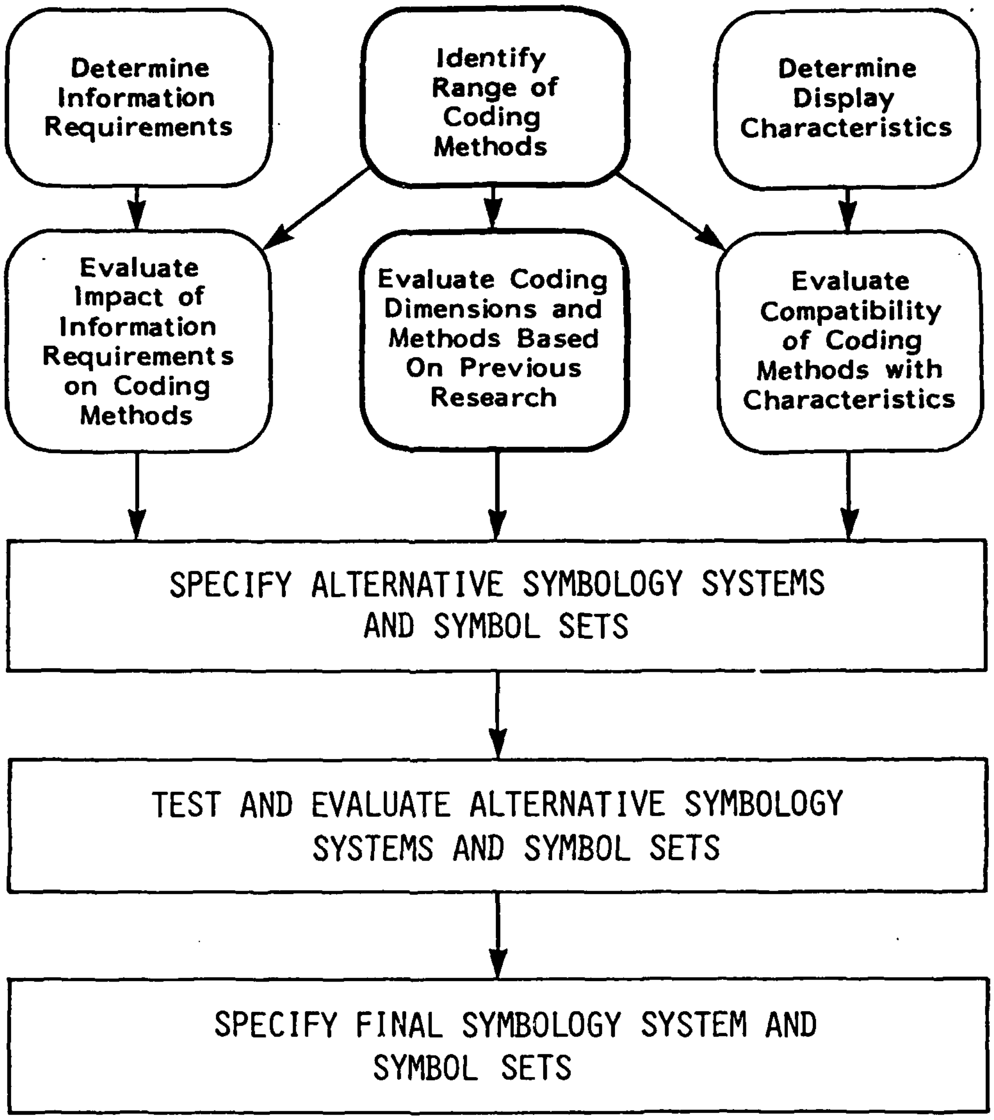


Figure 1. The six major tasks leading to the specification of alternative symbology systems and associated symbol sets. Tasks discussed in this report are outlined in bold lines. Also shown are the subsequent phases of test and evaluation, and specification of the final symbology system.

the results of the two tasks, boldly outlined in the figure, identification of the range of coding methods, and evaluation of coding dimensions and methods. To avoid the premature exclusion of any useful coding method, few design constraints were imposed during the identification of these methods. All coding methods potentially compatible with computer-generated display of topographic and tactical data were considered. Three general criteria were used to evaluate coding methods: amount of information conveyed, types of data coded, and value in aiding operator visual search of the display. The information reported here is applicable not only to the CGTD, but to a wide variety of symbology design projects.

IDENTIFICATION OF CODING METHODS

The fundamental components of any coding method are: **coding-dimension** and **symbol type**. Coding dimension is a perceived characteristic of stimuli that permits symbol discrimination; examples of coding dimensions are shape, size, color, brightness, and flash rate. Symbol type is the graphic form of symbols; point, line or area. A **coding method** is the conjunction of one or more coding dimensions and a single symbol type, such as size-coded line symbols or color-coded area symbols.

Ten separate coding dimensions that can be presented via computer-generated display are identified and discussed in this report. The coding dimensions of shape, alphanumerics, size, and color were gleaned from the cartographic literature (e.g., Arnberger, 1974; Morrison, 1974; Wood, 1968). The additional dimensions of inclination, flash rate, numerosity, brightness, and stereo depth emerged from reviews and guidelines found in the human factors literature (e.g., Grether & Baker, 1972; McCormick, 1976; Woodson, 1981). Finally, the dimension of apparent movement was extracted from experimental research dealing with perceptual processes (e.g., Rock, 1975; Scharf, 1975; Woodworth & Schlosberg, 1964).

The three types of symbols used to present topographic or tactical data--point, line, and area symbols—are often classified on the basis of the type of topographic feature they represent (e.g., Brandes, 1976; Keates, 1972; Morrison, 1974; U.S. Army FM 21-31; Wood, 1968). According to this classification, point symbols represent discrete points in the geography, line symbols represent features such as boundaries and routes, and area symbols represent areas that share geographic or political features. Keates (1972) pointed out that such a classification scheme is not absolute, since a given feature (such as an airport) may be represented as a point, a line, or an area depending upon the scale of cartographic representation. Although this relative nature of cartographic classification may not prove to be an obstacle in the final implementation of a topographic display system, it introduces unnecessary ambiguity in the evaluation of alternative methods of visual coding. For the purposes of the present discussion, the terms "point," "line," and "area" will be used to refer to the graphic form of symbols. Following this approach, point symbols are defined as discrete figural representations, line symbols as demarcations in a visual display, and area symbols as those used to distinguish demarcated areas from one another.

The matrix in Table 1 identifies the thirty unidimensional coding methods resulting from the three symbol types and ten coding dimensions. When two or

TABLE 1

CROSS-CLASSIFICATION OF UNIDIMENSIONAL METHODS OF VISUAL CODING

Coding Dimension	Symbol Type: Point	Line	Area
Shape			
Alphanumeric			
Size			
Numerosity			
Inclination			
Brightness			
Color			
Flash Rate			
Stereo Depth			
Apparent Movement			

more coding dimensions are combined with a single symbol type, multidimensional coding dimensions of an extremely rich variety result.

EVALUATION OF CODING METHODS

The three symbology evaluation criteria identified earlier--amount of information, compatibility with types of information, and aid in visual search--were applied to both unidimensional and multidimensional coding methods. The amount of information that can be conveyed by a coding method can be determined by the number of different symbols, varying along one or more dimensions, that can be identified absolutely (i.e., on a non-comparitive basis) by an observer. For example, the number of different point symbols varying in size that can be accurately identified determines the amount of information that can be conveyed by the method of size-coded point symbols. Coding methods also vary in their compatibility with different types of information. For example, numeric coding is much more compatible with the display of quantitative data than color coding. Finally, methods of coding vary in their ability to aid visual search. For example, flash-coded point symbols are more easily located than shape-coded point symbols.

SYMBOLOGY SELECTION

Figure 2 depicts the interrelationship of major factors that influence symbology selection.* Generally, the selection procedure is based upon a comparision between characteristics required of the symbology system and the characteristics inherent in the different coding methods. The factors outlined in bold are those discussed in the preceding paragraphs, and in subsequent sections of this report. The characteristics required of a symbology system, depicted on the left-hand side of Figure 2, are determined by the information-related tasks that must be performed by the observer. For example, determining the location of enemy antiaircraft weapons is critical during NOE flight (cf., Rogers, 1982). This task requires symbols that can be easily located in the display and that can provide information about types of weapons. Therefore, during the selection procedure, a method of coding must be selected to meet these requirements.

*Some major factors, such as display capabilities and symbol association value are not depicted in the simplified diagram of Figure 1. A more detailed presentation of the symbology selection process is provided in Section 14.

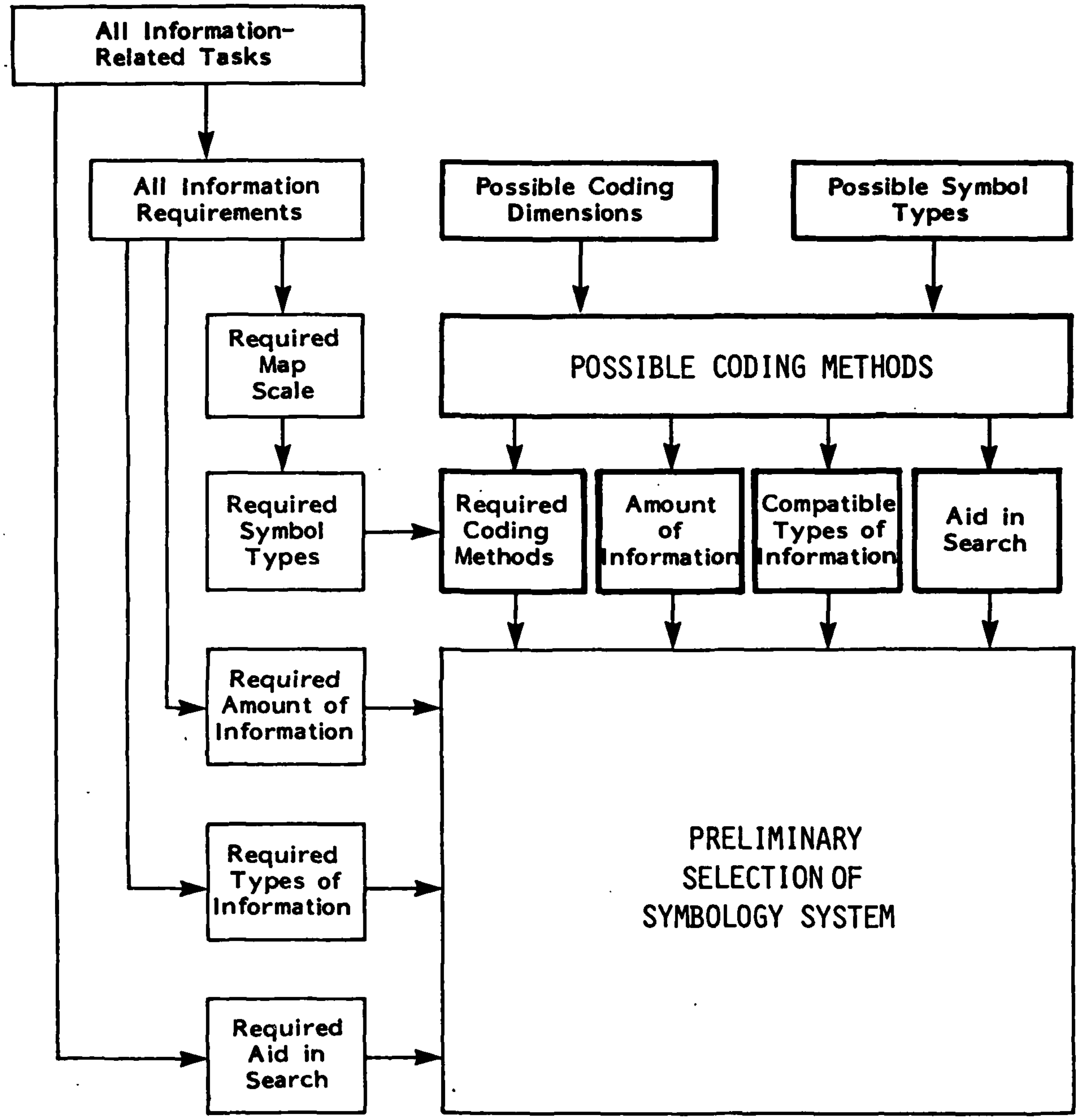


Figure 2. Major factors influencing the process of selecting a preliminary symbology system. Factors discussed in detail in this report are outlined in bold.

The subsequent sections of the report will examine each of the ten coding dimensions and the associated coding methods. A separate section is allocated to each coding dimension. Within each section, the presentation is organized as follows:

- **Definition.** A definition of the coding dimension, and a description of how it is implemented with each of the three symbol types are provided.
- **Important issues in coding.** The issues critical to coding symbols with each dimension are discussed.
- **General conclusions.** Research findings related to each of the important issues in coding are presented, along with the identification of areas in which research is lacking.
- **Applicable research.** A selective review of research applicable to the important issues in coding is presented.

The final sections of the report address the evaluation of separate coding dimensions, important issues in combining coding dimensions, and the presentation of a model for the development of symbology systems.

SECTION 2
SHAPE CODING

DEFINITION

The dimension of shape refers to the spatial form of a symbol. Alphanumeric symbols represent a special case of shape coding. Our extensive training with alphanumeric symbols has resulted in their becoming functionally distinct from other shape-coded symbols and they are discussed in the succeeding section. This section considers the use of shape as a dimension of coding in non-alphanumeric applications.

Shape-coded Point Symbols

A common classification within shape coding involves the distinction between geometric and pictorial symbols. Geometric symbols are abstract shapes or combinations of shapes that have been arbitrarily associated with classes of objects or concepts. A substantial amount of research has been conducted aimed at establishing readily discriminable and identifiable alphabets of geometric symbols. Figure 3 depicts a set of symbols used in a study conducted by Bowen, Andreassi, Traux, and Orlansky (1960) to determine the degree of confusability between forms. It is noteworthy that no identifiable subsets of features are systematically varied between the symbols in Figure 3. In contrast, a study conducted by Williams and Falzon (1963b) used the symbols shown in Figure 4 in which lines were systematically used to differentiate circles, squares, triangles, and diamonds.

Pictorial symbols are simplified reproductions of classes of objects or concepts. Such symbols are distinguished from geometric symbols on the basis of their "iconicity," or tendency to be accurately interpreted without training. A number of references in the design literature have cataloged sets of previously designed pictorial symbols (e.g., Dreyfuss, 1972; Kepes, 1966; Modley, 1976; Modley & Lowenstein, 1952; Shepard, 1971; U.S. Department of Transportation, 1974). A survey of these references is useful for a review of alternative styles that have been used in the design of pictorial symbols. One of the major differences in style involves the degree to which detail is omitted from the symbol. A sample of simplified, yet easily interpreted, pictorial symbols used to depict events for the 1972 Olympic games is shown in Figure 5.

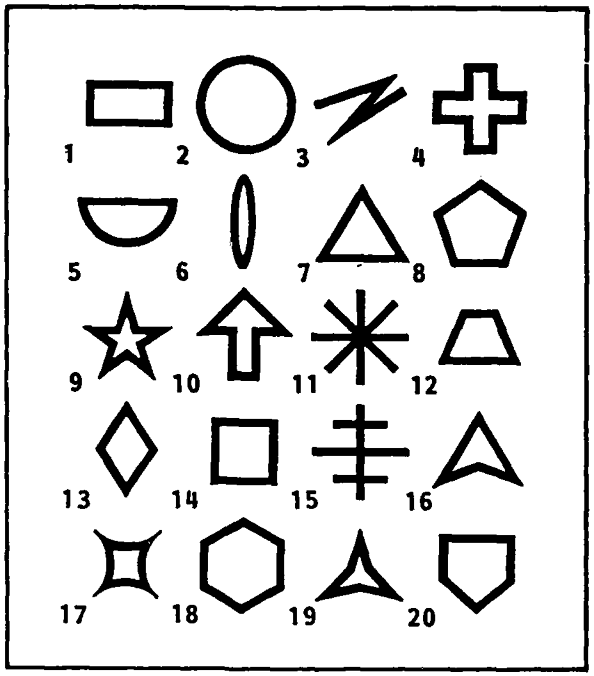


Figure 3. Geometric symbols used by Bowen et al. (1960).

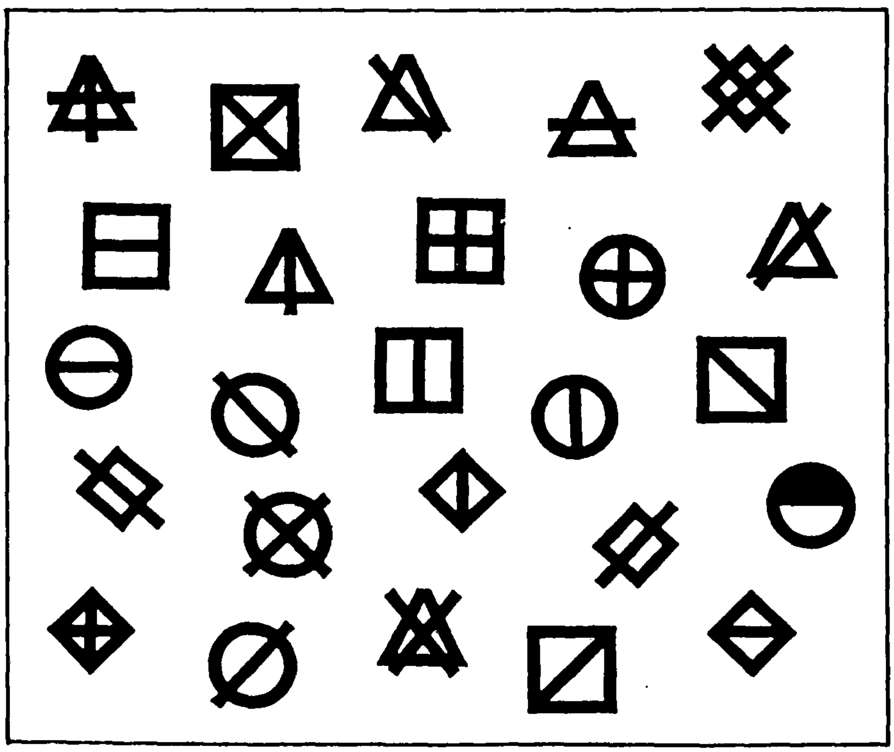


Figure 4. Geometric symbols used by Williams and Falzon (1963b).

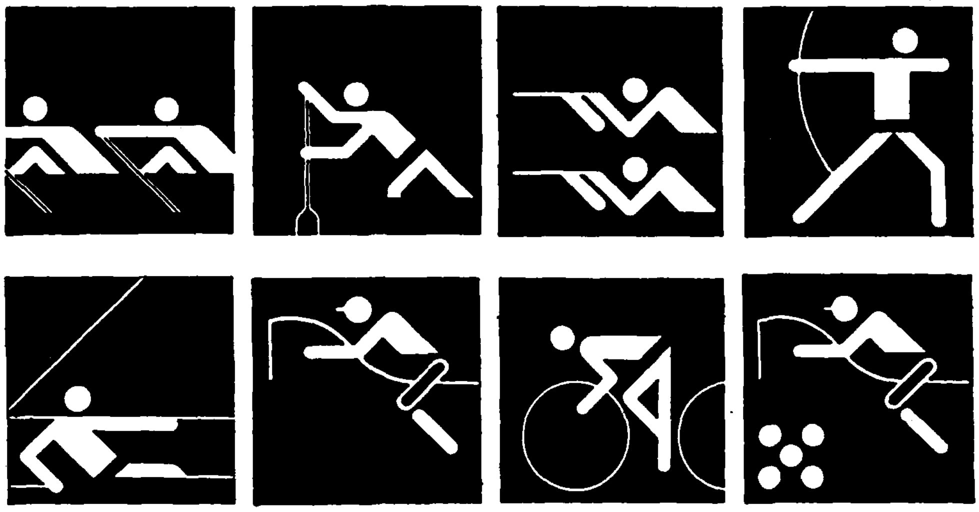


Figure 5. A sample of pictorial symbols designed for the 1972 Olympic games.

Shape-coded Line Symbols

Shape coding can be used to vary the appearance of display demarcations through differences in continuous line forms, repetition of individual geometric symbols, and repetition of symbol patterns. Many of the methods employed to make lines discriminable from one another depend upon the use of point symbols that are readily differentiated. The set of twenty-five lines developed by Schutz (1961a, 1961b), shown in Figure 6, represent some methods for differentiating lines on the basis of shape and symbol pattern coding.

Shape-coded Area Symbols

Demarcated areas of a visual display can be varied using shape coding by repeating a point symbol, repeating a line symbol, or displaying different point and/or line symbols in an area. Figure 7 depicts a number of different area symbols used to code the mineral composition of geological areas.

IMPORTANT ISSUES IN SHAPE CODING

Shape coding represents one of the more flexible dimensions of coding available for use in a symbology system. When selecting a shape-code alphabet,

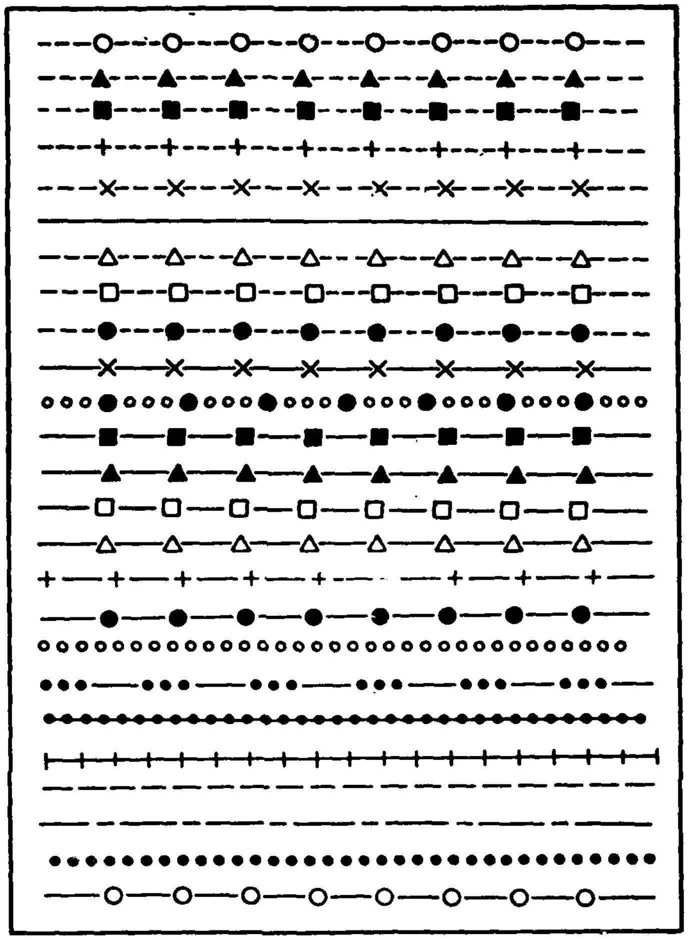


Figure 6. A set of 25 shape-coded line symbols developed by Schutz (1961a, 1961b).

however, the factors that affect symbol identification and comprehension must be considered.

The most important factor affecting the ability of an observer to identify a specific symbol is the degree to which that symbol is confused with or discriminated from other symbols. Both the shapes and the number of different symbols in a shape-code alphabet influence symbol discriminability.

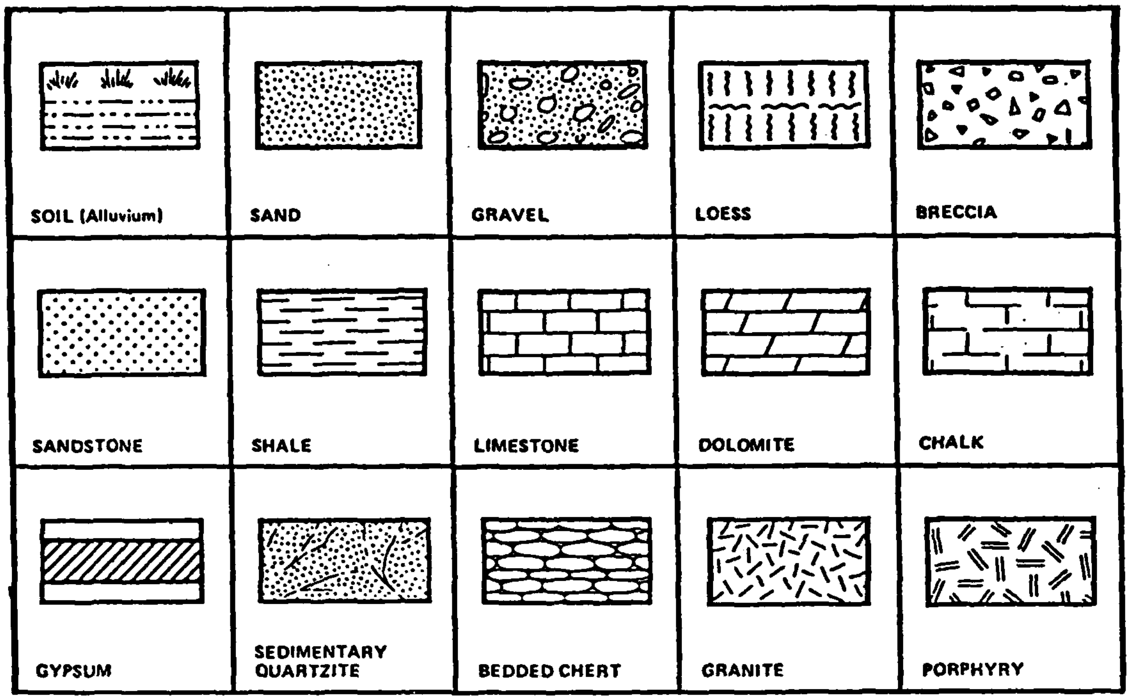


Figure 7. A sample of shape coded area symbols used to code the mineral composition of geological areas.

Discriminability is a necessary but insufficient condition for symbol comprehension. A symbol must be discriminable from other symbols on the basis of its shape if it is to be included in a shape-code alphabet. However, the ease with which people learn the coded meaning of a symbol is influenced by past experience with symbols of similar shape.

GENERAL CONCLUSIONS

Most of the research in shape coding has involved hard copy displays, which tend to have better resolution than electronic displays. However, some tentative conclusions can be made about shape coding in general, assuming that a display with adequate resolution is employed. These conclusions are:

- Simple geometric symbols are identified more accurately and quickly than complex geometric symbols.
- A limited set of basic geometric forms, such as the circle, square, semicircle, cross, and triangle can be used together in a single set of shape-coded symbols.

- The size of a set of highly discriminable geometric symbols can be increased by the use of modifying slashes and lines.

- In evaluating the discriminability of a shape-coded symbol it is important to consider all other shape symbols that are to be used in a symbology system, since symbol discriminability is dependent upon the similarity of form between symbols.

- Shape-coded symbols that are commonly interpreted as representing a specific object or concept require less training to be accurately identified than many symbols that are traditionally used.

No general conclusion can be drawn from the existing research concerning the maximum size of a shape-code alphabet. Geometric symbols presented via hard copy can be used to construct sets of twenty symbols or more. The maximum size of a set of pictoral symbols is much greater. For both types of symbols, the mode of display and the tasks that must be performed by the observer are critical factors in selecting a symbol set. Therefore, a proposed shape-code alphabet should be assessed using an operational display and operationally valid tasks prior to implementation.

APPLICABLE RESEARCH

A substantial number of experimental studies have attempted to specify easily identifiable shape codes. Much of this early research focused on claims by Gestalt psychologists that the circle was the "simplest" figure and could be identified more easily than other forms. This theory of "simplicity" or "good figure" was open to direct empirical test. The Gestalt school was shown to be incorrect in their assertion, as many investigations demonstrated that absolute detection threshold and peripheral detection for triangles, rectangles, or crosses was equal or superior to that of circles (e.g., Casperson, 1950; Collier, 1931; Hanes, 1950; Helson & Fehrer, 1932). More recent research has been directed towards the use of relatively large sets of shape-coded symbols for display. The more important research of this type is selectively reviewed in the remainder of this section.

Sleight (1952) conducted a study in which subjects were required to sort one of 26 forms (see Figure 8) displayed on a table before them. There were significant differences in the sorting time for designated forms, with the fastest forms being the swastika, circle, crescent, airplane, cross, and star, in that order. Perhaps the most important finding by Sleight was that the set of similar polygons--the pentagon, hexagon, octagon, and heptagon—were all sorted slowly. This finding suggests that the relative discriminability of forms is partially dependent upon the particular forms that comprise an alphabet. The primary implication of this finding is that identifiability of any shape code cannot be specified without determining the degree to which it is confused with other symbols to be used in an alphabet.

Gerathwohl and Rubinstein (1953) compared identification accuracy of four shapes (the circle, square, triangle, and cross) on a PPI scope under varying levels of contrast and simulated range. Subjects were required to identify shapes in a specific ring of the scope. Triangles were identified most accurately, followed by the square, circle, and cross, in that order. Although the results of this study has implications for legibility of shapes (simulated range was found to affect accuracy), the results have few implications for the selection of a substantial number of easily identifiable geometric symbols.

Bowen, Andreassi, Truax, and Orlansky (1960) conducted a series of experiments in an attempt to specify an optimum shape code alphabet for CRT type displays. In the first experiment, observers attempted to identify 20 different

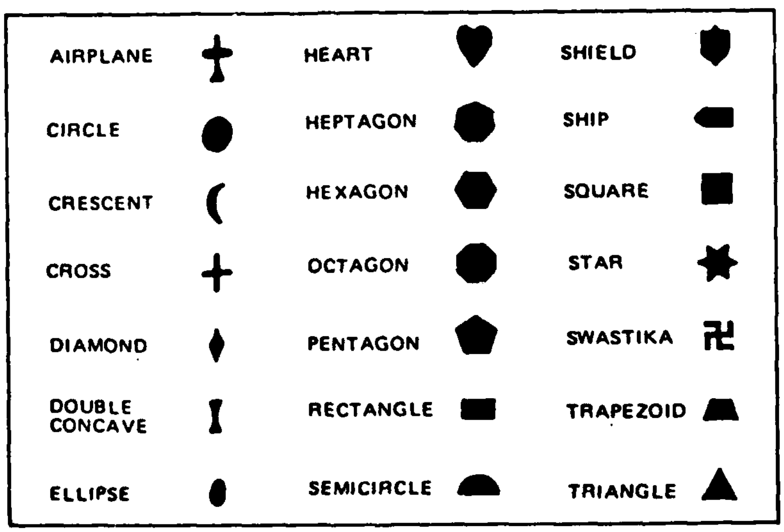


Figure 8. Forms and labels used by Sleight (1952).

symbols (see Figure 3, page 10). The observers viewed a slide of one symbol and then attempted to identify the symbol in a booklet containing all 20 symbols. Table 2 presents the identification accuracy for each symbol. Because there was confusion between symbols, Bowen and his colleagues recommended that no more than ten different symbols be employed in a shape alphabet. The specific symbols that were recommended from their analysis of a confusion matrix are provided in Table 3.

TABLE 2

PERCENTAGE OF CORRECT RECOGNITION FOR THE
20 GEOMETRIC SHAPES USED BY BOWEN et al. (1960)
(Symbol numbers refer to identification numbers in Figure 1)

Symbol No.	Percentage Correct	Symbol No.	Percentage Correct
1	91.6	11	78.5
2	89.8	12	75.6
3	86.9	13	77.9
4	86.9	14	50.6
5	83.9	15	76.2
6	88.1	16	55.3
7	87.5	17	45.8
8	83.3	18	72.0
9	83.9	19	55.9
10	86.3	20	69.0

TABLE 3

OPTIMUM SETS OF SYMBOLS RECOMMENDED BY BOWEN et al. (1960)

Number of Symbols in Set	Recommended Symbols
2	1 & 2; or 1 & 3; or 2 & 3; or 7 & 14; or 5 & 7; or 5 & 14
3	1, 2, & 3; or 5, 7, & 14
4	1, 2, 3, & 4; or 5, 6, 7, & 14
5	1, 2, 3, 4 & 5; or 4, 5, 6, 7, & 14
6	1, 2, 3, 4, 5, & 6
7	1, 2, 3, 4, 5, 6, & 7
8	1, 2, 3, 4, 5, 6, 7, & 8
9	1, 2, 3, 4, 5, 6, 7, 8, & 9
10	1, 2, 3, 4, 5, 6, 7, 8, 9, & 10

Williams and Falzon (1963a) conducted an experiment in an attempt to determine the influence of some basic characteristics of shape symbols on the speed and accuracy of identification. The experiment also assessed the effect of viewing angle and display arrangements on the two behavioral measures. The authors selected 100 shape symbols (see Figure 9), 90 of which were divided into six categories on the basis of two shape-related characteristics termed "form class" and "form dimension." The authors distinguished between three form classes: simple geometric forms, combined geometric forms which were constructed by combining two or more simple geometric shapes, and pictorial forms. In addition,

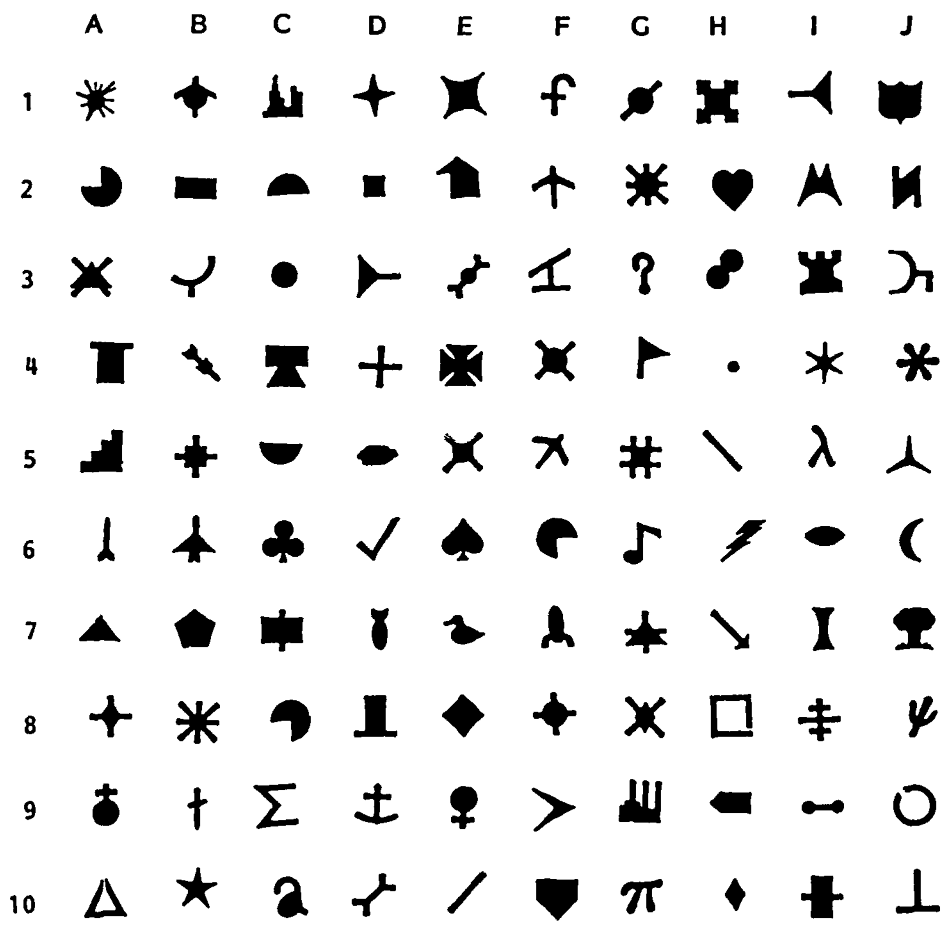


Figure 9. Geometric symbols used by Williams and Falzon (1963a).

two form dimensions were specified: **area** forms which were solid forms and **perimeter** forms which were either outline forms or forms with intersecting lines. Each of 90 symbols was assigned exclusively to one of these six shape-related categories. Table 4 gives these assignments for the forms presented in Figure 9.

The identification task performed by each of nine subjects in Williams and Falzon's (1963a) study consisted of viewing individual forms for .5 second then scanning through an array of 100 different forms searching for the one presented. The effects of the shape-related factors on identification accuracy and speed were assessed statistically. The "class" of a form was found to influence accuracy. Simple forms were recognized most accurately, followed by pictorials and combined geometrics. However, accuracy for a form class was also influenced by the "dimension" of the form. For simple geometric symbols, identification of perimeter and area symbols was the same. For combined geometric forms, area types were identified most accurately. But for pictorial forms, perimeter type symbols

TABLE 4

CLASSIFICATION BY WILLIAMS AND FALZON (1963a) OF SYMBOLS TO EXPERIMENTAL CATEGORIES

Simple X Perim.	Simple X Area	Comb. X Perim.	Comb. X Area	Pict. X Perim.	Pict. X Area	Unclassified
A-10	A-5	A-8	A-3	A-6	A-1	A-2
B-10	A-7	B-5	A-9	B-3	A-4	C-5
D-1	B-2	B-8	C-4	B-4	B-1	C-9
D-4	B-7	D-6	C-7	B-9	B-6	C-10
E-10	C-2	D-10	D-3	D-7	C-1	F-1
F-9	C-3	E-3	E-2	D-9	C-6	F-3
H-4	C-8	E-5	E-9	F-2	D-5	G-10
H-5	D-2	F-4	G-5	F-5	D-8	H-7
H-8	E-1	F-8	G-7	G-3	E-6	I-5
H-10	E-4	G-1	H-1	G-4	E-7	J-8
I-4	E-8	G-2	H-3	G-6	F-7	
I-7	F-6	G-8	I-1	G-9	H-2	
J-4	FD-10	I-8	I-2	H-6	I-3	
J-5	H-9	I-9	I-10	J-3	J-1	
J-9	I-6	J-10	J-2	J-6	J-7	

were recognized most accurately. The effects of these factors on identification reaction time was less complicated. The type of "form class" significantly influenced identification time, with simple geometric being identified fastest, followed by pictorial and combined geometric, respectively. The "dimension" of a form also influenced this measure, with area symbols being identified faster than perimeter symbols.

After reviewing their findings, Williams and Falzon (1963a) made three recommendations concerning the use of geometric symbols. First, simple geometric symbols were recommended to minimize identification errors and search time when viewing from a straight-on position. Second, simple geometric or pictorial perimeter symbols were recommended when viewing displays from the side. Finally, combined geometric forms were not recommended. This final recommendation, if accepted, has major implications for the symbology system designer, since it greatly limits the size of a shape-coded symbol alphabet.

Williams and Falzon (1963b) conducted a second experiment to obtain an optimal symbol set for complex Air Force displays. They constructed a new set of 25 symbols (see Figure 4, page 10), based primarily on their finding that solid geometric-type symbols were not suitable for this application. Observers performed an identification task using the new symbol set under viewing conditions identical to the first study.

In considering the types of confusions made by subjects, the authors noted that symbols constructed from diamonds were often confused with other forms; circles with lines and squares with lines were recognized at satisfactory levels of accuracy; and outlined triangles were superior to diamonds, but identified less accurately than circles and squares. The authors noted that many of the specific confusions between circles and squares involved additional lines extending outside of the shape perimeter. They report that they were able to reduce these errors by shortening these lines. However, subsequent evaluations of the modified symbols have not been reported.

In a portion of a frequently cited study conducted by Smith and Thomas (1964), three types of shape codes were compared by measuring the time required to count occurrances of a designated symbol in a 100-item display. Each set of shape-coded symbols consisted of five items (see Figure 10). One set of symbols

COLORS (MUNSELL NOTATION)	MILITARY SYMBOLS	GEOMETRIC FORMS	AIRCRAFT SHAPES
GREEN (2.5 G 5/8)	RADAR	TRIANGLE	C-54
BLUE (5 BG 4/5)	GUN	DIAMOND	C-47
WHITE (5 Y 8/4)	AIRCRAFT	SEMI CIRCLE	F-100
RED (5 R 4/9)	MISSILE	CIRCLE	F-102
YELLOW (10 YR 6/10)	SHIP	STAR	B-52

Figure 10. Color and shape symbols used by Smith and Thomas (1964).

were pictorial military symbols selected to represent an easily discriminable code, since they varied in size and orientation, as well as in shape. A second set of symbols was based upon standard geometric symbols. The third set of symbols, based on aircraft silhouettes, was selected to represent a fairly difficult shape code, since each shape was judged by the authors to be similar to at least one other member of the set. For the experimental comparison between shape codes, five 100-item slides were constructed. The slides differed in the number of each specific symbol. Time to count symbols and the number of trials in which errors in counting occurred were analyzed separately. Counting time for the similar aircraft symbols was approximately twice as long as counting time for either geometric forms or the military codes. The percent of trials in error was also substantially higher for the aircraft symbols, compared to the other two types of symbols. It is interesting to note that one of the military symbols was an aircraft symbol. Smith and Thomas note that this symbol was counted much more quickly and accurately than any of the symbols in the aircraft shape code. The authors state that "this is a phenomenon familiar to practical display designers who have discovered it is often a wise precaution to verify empirically the discriminability of a particular symbol set proposed for use, rather than to rely on data gathered in some different display context."

In selecting a shape-coded alphabet, attention should also be given to symbol comprehension, since many shape codes can take advantage of existing stereotypes in symbol interpretation. In considering the issues related to comprehension, a number of literature reviews suggest that shape coding should be pictorial (i.e., Barmack & Sinaiko, 1966; Grether & Baker, 1972; Honigfeld, 1964; Meister & Sullivan, 1969), since the coded meaning of this type of symbol can be more accurately interpreted. Grether and Baker (1972) make the more general statement that a symbol designer should select shapes that are "compatible with and have association with the objects coded."

The methods of obtaining estimates of association value for symbols are straightforward (e.g., Davis, 1969; Hemingway, Kubala & Chastain, 1979; Howell & Fuchs, 1968). However, methods for the development of symbols with high association value are not so clear-cut. In a review of pictorial symbol discriminability, Green (1979) notes three approaches commonly adopted for pictorial symbol development. The most popular approach is to use whatever symbols are found in the **Symbol Sourcebook** (Dreyfuss, 1972). However, the comprehensibility of forms in this book has not been evaluated. A second common approach is for the symbol designer to invent a symbol that he or she thinks is appropriate (e.g., Bedno, 1972; Purcell, 1967; Torpy, 1975). The third approach, termed the "population stereotype" approach, is that of obtaining sample drawings from user populations and summarizing the results (e.g., Brainard, Campbell & Elkin, 1961; Howell & Fuchs, 1968; Krampen, 1969; Torre & Sanders, 1958). The work of Howell and Fuchs involved the development and evaluation of an alternative military tactical symbology, and is reviewed below.

Howell and Fuchs (1968) conducted six studies which examined the feasibility of constructing symbols based upon population stereotypes. The procedure used for symbol generation was to request 20 university students to draw a set of five drawings for each of 52 military concepts which were defined for the students (see Table 5). The resulting 5200 drawings were then analyzed and summarized independently by three experimenters. Finally, the six most frequently drawn symbols for each concept were selected for use in subsequent experiments. In Experiment 1, 20 different students ranked each of the drawings with respect to their applicability to each concept, resulting in a separate index of symbol stereotype. Experiments 2 and 3 consisted of further evaluations of the degree of symbol stereotype for the resulting drawings.

TABLE 5

A COMPLETE LISTING OF THE INTELLIGENCE CONCEPTS FOR WHICH SYMBOLS WERE DEVELOPED IN EXPERIMENT I (Howell & Fuchs, 1968)

Missile Site Readiness	**Anti-Jamming Capability**
Construction completed	Barrage
Under construction	False target
Missile being tested	Sweep
Missile ready to fire	Random
Missile being fueled	Spot noise
Type of Missile	**Radar**
Surface to surface	Radar site
Surface to air	Early warning radar
Air to air	Surface to air radar
Surface (underwater) to air	Nike radar
Air to surface	Gap filler radar
Army Installations	**Defense Capability**
Anti-aircraft artillery	Poor
ICBM	Fair
Anti-aircraft missile	Good
IRBM	Excellent
Anti-missile missile	Superior
Agency Supporting Industry	**Type of Industry**
All military	Gas plant
Industry	Lead refinery
Army	Petroleum refinery
Navy	Aluminum plant
Air Force	Steel mill
Fuel and Ammunition Storage	**Aircraft**
Tanks	Tanker aircraft
Underground	Fighter aircraft
Sheds	Short range bomber
Caves	Transport aircraft
Bunkers	Long range bomber
	Air field

In Experiment 4, Howell and Fuchs compared rate of learning three types of symbols: those judged to be highly applicable, symbols judged to have low applicability, and number codes (see Figure 11). Separate groups of subjects were trained to identify each symbol from one of the three sets by responding with the military concept paired with the symbol. All subjects continued practice over successive days until they were able to name an entire set of symbols correctly once. Following training, each symbol was presented tachistoscopically for .03, .12, .21, and .30 seconds for retention tests, in which both speed and accuracy of naming, or comprehension, was recorded.

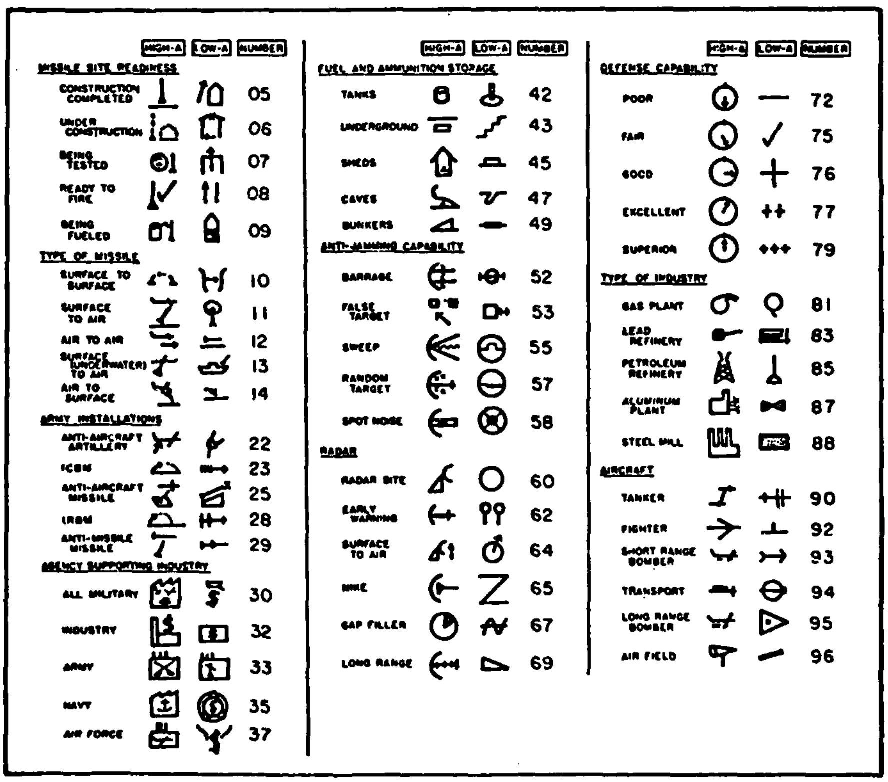


Figure 11. Symbol category labels and corresponding high-applicable symbols, low-applicable symbols, and number symbols used by Howell and Fuchs (1968, Experiment 4).

The results of training during Experiment 4 indicated that the high-applicable symbols were learned in the least number of trials, followed by the low-applicable symbols and the numbers, respectively. The results of the tachistoscopic retention tests indicated that accuracy of identification was high for all symbol sets (mean accuracy was 93.5% across all symbol sets and exposure durations). However, speed of identification differed significantly between the three sets of symbols (see Table 6). The results suggest that overlearned symbols can be accurately identified, regardless of their judged applicability. However, the large difference in identification speed between pictorial symbols and numerals (Table 6) suggests that less processing, or recoding, is required to identify applicable symbols than unrelated symbols.

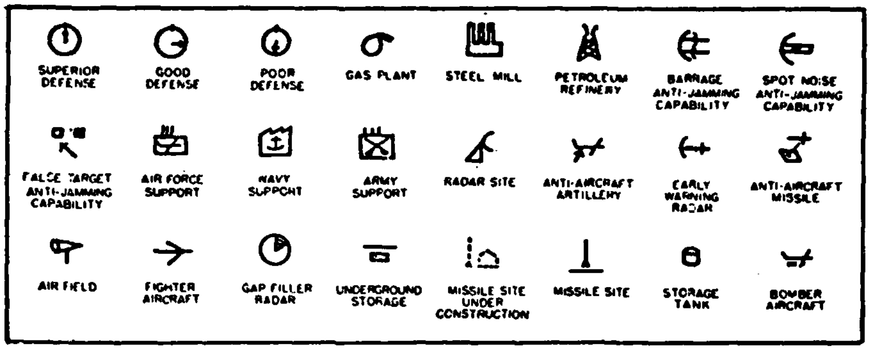
In Experiment 5, Howell and Fuchs conducted a study similar to the preceding one in which 24 of the highly applicable symbols were compared with 24 traditional military symbols (see Figure 12). There is not a complete match in the military terms used for the two symbol sets shown in Figure 12, however, in a pilot study, Howell and Fuchs demonstrated that the two sets of terms did not differentially affect rate of learning. Observers learned to identify symbols from either set until they could identify all items correctly. Following training, tachistoscopic identification was evaluated with the same procedure that had been used in Experiment 4. Analysis of results indicated that fewer training trials were required to learn to identify the symbols constructed by Howell and Fuchs than the traditional symbols. However, no differences in identification accuracy or speed during the retention test were indicated by the analyses.

TABLE 6

MEAN RESPONSE LATENCIES (IN SEC) OBTAINED FOR THE THREE EXPERIMENTAL CODES UNDER FOUR EXPOSURE DURATIONS IN EXPERIMENT IV (Howell & Fuchs, 1968)

	Exposure duration (sec.)			
Code	.03	.12	.21	.30
High-A	1.44	1.31	1.32	1.30
Low-A	1.50	1.38	1.41	1.38
Numbers	2.27	2.15	2.25	2.15

HIGH-APPLICABLE SYMBOLS AND TERMS



TRADITIONAL MILITARY SYMBOLS AND TERMS

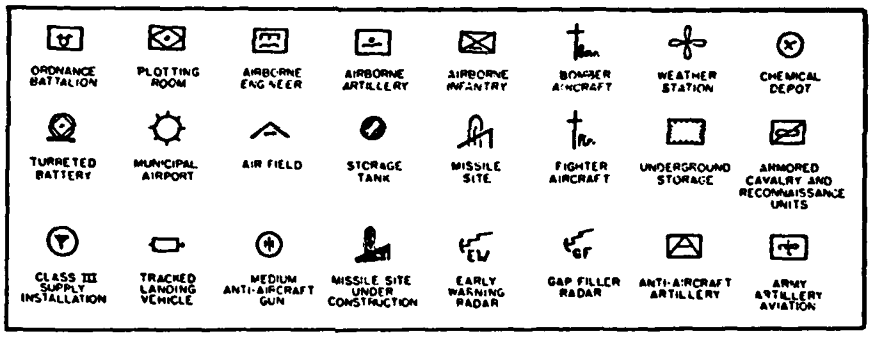


Figure 12. The two sets of symbols and terms used by Howell and Fuchs (1968, Experiment 5).

The research by Howell and Fuchs (1968) demonstrated the advantage, in terms of required training time, for designing pictorial symbols based upon user population input. The research also demonstrated the advantage of pictorial symbols in terms of speed of identification when symbols are presented briefly in an expected location. However, the results of this study are not necessarily applicable to either random search tasks or operational conditions.

SECTION 3
ALPHANUMERIC CODING

DEFINITION

Alphanumeric symbols are shape symbols that have been incorporated into a language or mathematical system. The three most commmon alphanumeric symbol systems used in the U.S. are the Morse code, Braille, and the Roman letter/Arabic numeral system. The symbols comprising the Morse code and Braille systems are constructed in highly standardized formats, since both are based on highly constrained rules for character generation. In contrast, there is a great deal of variety in the shape detail, or "font," used in constructing the more common Roman letters and Arabic numerals. The definition of font proposed by Semple, Heapy, Conway, and Burnette (1971) will be adopted for the present discussion. These authors define font as "the fundamental geometry or style of a particular set of alphanumerics." This section considers a number of alternative fonts that could be used for alphanumeric coding.

IMPORTANT ISSUES IN ALPHANUMERIC CODING

Because of the familiarity of alphanumeric symbols, they can be identified quickly and accurately in several of the more common fonts. The measure of alphanumeric identification is commonly referred to as legibility. Legibility can be operationally defined as the speed or accuracy of alphanumeric identification.

The most general factor affecting legibility is the mode of symbol display (i.e., hard copy, CRT display, dot matrix display, etc.), because specific characteristics of font, such as character width-to-height ratio, stroke width-to-height-ratio, compactness of elements composing a stroke, and the use of serifs are often dependent upon the mode of display. The effects of the specific characteristics of font on alphanumeric legibility have been investigated, and a brief survey of this research is provided in this section.

Several factors other than font have also been shown to affect alphanumeric legibility. Some of the more important factors of this type are exposure duration, ambient illumination, symbol display contrast ratio, degree of blur, and symbol edge contrast ratio. Because they do not pertain directly to coding dimensions, these factors will not be considered in the present discussion. For summaries of research related to these factors, the reader may refer to a number of extensive reviews. See Cornog & Rose, (1967) for a review of factors other than font that affect hard copy legibility. See Semple et al. (1971); Shurtleff (1980); Snyder (1980); and Vanderkolk, Herman, & Hershberger (1975) for reviews of electronically displayed character legibility.

GENERAL CONCLUSIONS

Literally hundreds of studies have investigated factors that affect the legibility of alphanumerics displayed by hard copy techniques. However, the relatively small number of studies investigating legibility of electronically displayed alphanumerics illustrate the difficulty of making generalizations across types of displays and display conditions. Some of the general conclusions that can be drawn from research investigating the influence of font on alphanumeric legibility are listed below.

- The NAMEL and Lincoln/Mitre fonts have been shown to be highly legible for hard copy display.
- Certain unorthodox, geometrically styled numerals have been shown to be more legible than more traditional fonts when displayed via hard copy. However, the legibility of complete sets of such unorthodox alphanumerics has not been assessed; and it is probable that confusion between letters and other geometric symbols would occur if such a front were designed.
- The research on font legibility with CRT displays is inconclusive. No font has been shown to be clearly superior with this type of display, although several styles have been shown to be reasonably legible.
- The legibility of hard copy fonts on dot matrix displays depends upon the specific font adaptation used, matrix size, matrix shape, compactness of matrices, and the arrangement of matrix emitters.
- Most importantly, research in legibility indicates that type of display, environmental condition, and observer tasks can vary so widely between operational settings that legibility research should be conducted in simulated operational settings prior to adopting an alphanumeric font.

APPLICABLE RESEARCH

A number of investigators and designers have attempted to design maximally legible hard-copy alphanumeric fonts. An early attempt by Mackworth

(1944) resulted in the Mackworth style, which was used on air raid sector maps in Great Britain. In evaluating his new design, Mackworth conducted a study in which he compared identification accuracy using his symbol set with that of letters similar to the AND 10400 style and numbers similar to the Leroy style (see Figure 13). Symbols ranging in height from 6 to 9 minutes of visual arc were

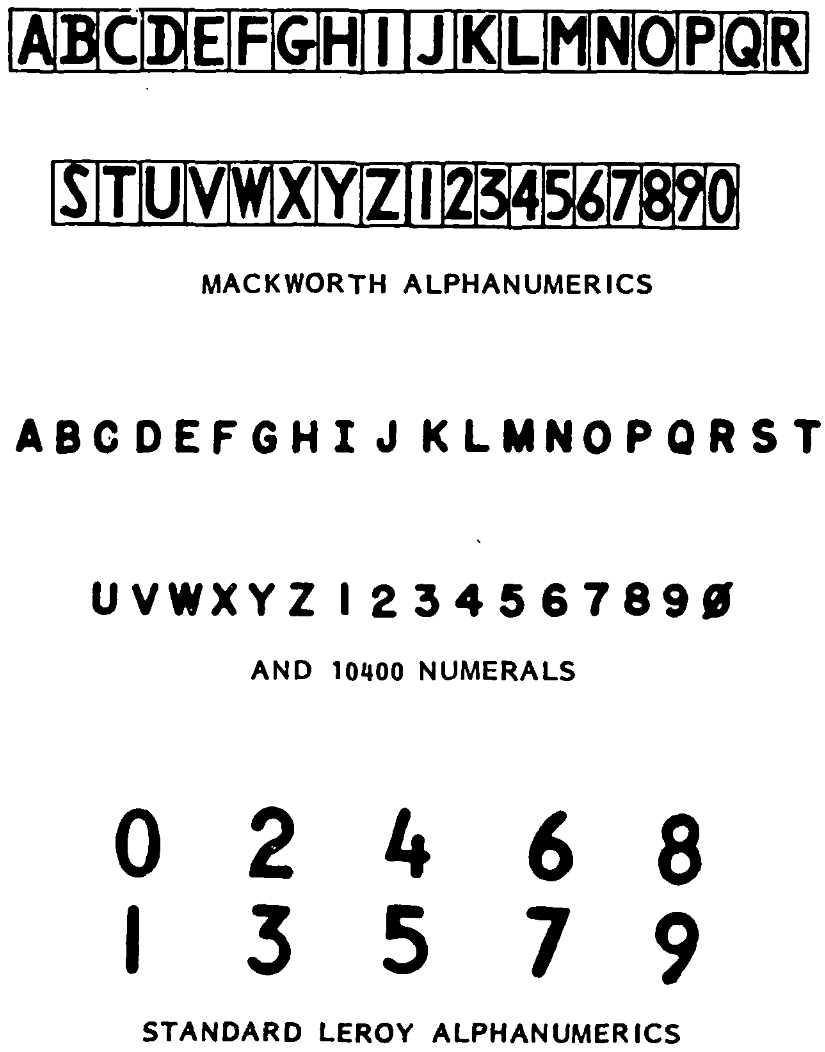


Figure 13. Three fonts: Mackworth alphanumerics, AND 10400 numerals, and standard Leroy alphanumerics.

presented individually for approximately 1.5 seconds at 10 fL illumination. The symbols selected from the modified AND 10400 and Leroy styles were presented as dark on an orange background while the Mackworth symbols were presented as dark on a yellow background. The Mackworth sytle was found to be more accurately identified under these conditions. However, as Crook and Baxter (1954) noted, the use of different background colors in Mackworth's study probably resulted in a higher brightness contrast for the Mackworth symbols and this may have contributed to their superior identification.

In another comparison of hard copy fonts, Brown (1953) compared the legibility of NAMEL letters with a set called Garamond Bold (see Figure 14). Two major differences in the fonts were the uniformity of stroke-width-to-height ratio and the use of serifs, which are short lines which stem from the ends of symbol strokes. As can be seen in Figure 14, the NAMEL font does not have these characteristics, whereas the Garamond Bold font incorporates both. Brown compared the identification accuracy of 19 letters (B,I,J,K,Q,V, and W were excluded) at .20 second exposures and five levels of illumination ranging from 0.30 to 3.30 fL. NAMEL letters were found to be more accurately identified, with the greatest differences occurring at the two lowest levels of illumination, 0.30 and 0.80 fL. However, it should be noted that the stastical significance of the differences found in this study were not reported. It is also important to note that since both serifs and stroke-width-to-height ratios were varied, it is inappropriate to form conclusions about their unique influence on legibility.

ACDEFGHLMNOPRSTUXYZ

ACDEFGHLMNOPRSTUXYZ

Figure 14. Garamond Bold (upper) and NAMEL (lower) letters used by Brown (1953).

Showman (1966) used hard copy materials to compare a refined version of Mackworth's font called the Lincoln/Mitre font (see Figure 15) with the Leroy font, which had been used extensively in commercial art and advertising. Nine subjects were presented single letters with a 0.01 second viewing time and brightness contrast ratios ranging from 4:1 to 10:1. Lincoln/Mitre letters were identified more accurately at each brightness contrast ratio. However, the extremely brief exposure durations used in this study limit the application of the experimental findings.

Lansdell (1954) took a more unorthodox approach to font design by constructing a set of numerals incorporating geometrical shapes (see Figure 16). Lansdell found that these numerals were more accurately identified than Mackworth numerals at an exposure duration of 0.6 second and brightness level of 10 fL. Foley (1956) revised the Lansdell numerals (see Figure 17) and made a

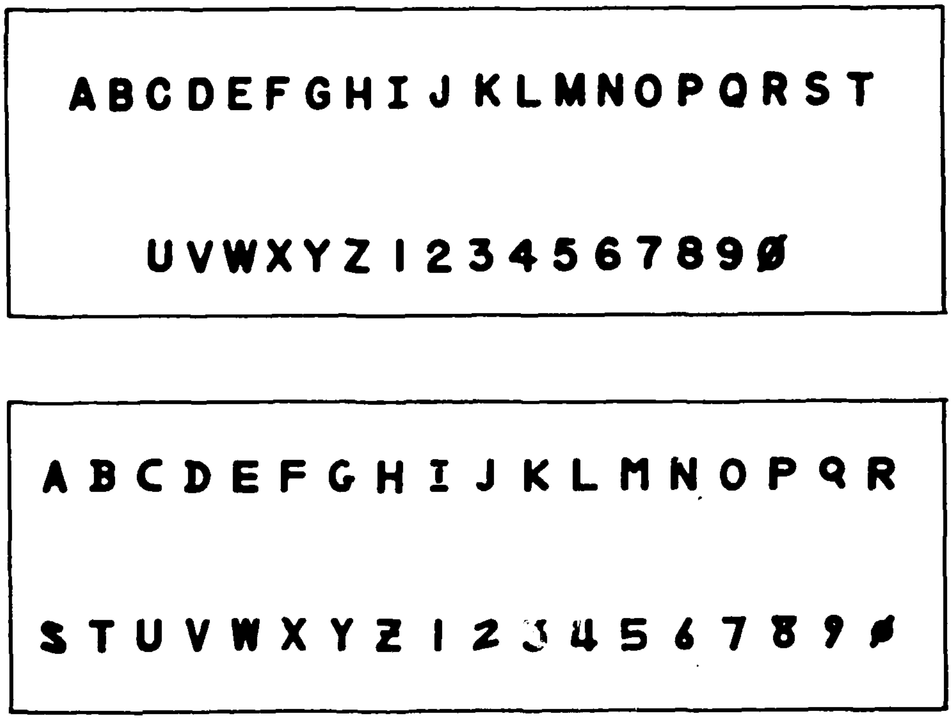


Figure 15. Lincoln/Mitre alphanumerics (upper) and standard Leroy alphanumerics (lower).

Mackworth numerals at an exposure duration of 0.6 second and brightness level of 10 fL. Foley (1956) revised the Lansdell numerals (see Figure 17) and made a second comparison with the Mackworth font. He found that for exposure durations ranging from 0.3 to 1.3 seconds and brightness levels between 10 and 50 fL, identification accuracy of the Foley numbers was significantly better than for the Mackworth. No comparison between the Lansdell and Foley sets has been reported.

Although such unique numeral sets as the Lansdell and Foley may be useful in certain limited applications, it is important to note that letter alphabets were not constructed. It has yet to be demonstrated that such a design approach could result in an identifiable set of letters and numerals. Additionally, it should be noted that confusions between some of these numerals and geometric symbols would be likely.

In summing up their review of hard copy font comparisons, Semple et al. (1971) concluded that the results of these studies do not support recommendations concerning the influence on legibility of such features as the uniformity of stroke-width-to-height ratio or the use of serifs. Both the NAMEL and Lincoln/Mitre fonts have faired well in such comparisons and are probably suitable for use in a wide variety of applications. However, the applicability of research with hard copy fonts to electronic displays is limited since such characteristics as symbol shape, character width-to-height ratio, stroke width-to-height ratio, brightness contrast, and edge sharpness are influenced by the method of symbol generation.

Figure 16. Landsdell numerals.

Figure 17. Foley numerals.

In their review of alphanumeric legibility, Vanderkolk et al. (1975) noted that most legibility research using electronic displays has been conducted on CRT displays. The difference in symbol generation between CRT displays and dot matrix displays leads to the same difficulties in research applicability mentioned above in reference to hard copy comparisons. Therefore, legibility research using each type of display must be considered separately.

One of the early attempts to design an optimal font for video CRT displays was conducted by Rowland and Cornog (1958), who developed a new set of uppercase alphanumerics designated the Courtney font (see Figure 18). Using group subjective evaluations as the only criterion for font quality, Rowland and Cornog concluded that the Courtney font was superior to many existing fonts. The apparent superiority of the Courtney font was subsequently reconfirmed by Moore and Nida (1958), who compared the new font with 67 other styles. However, these investigators also employed a subjective method of evaluation.

Shurtleff and Owen (1966) demonstrated the danger of relying upon subjective evaluations in comparing fonts. These investigators compared the Courtney font with the standard Leroy font using a Miratel 14-inch video monitor and a 525-line Fairchild television camera. Speed and accuracy of symbol identification was measured for symbol resolutions of 6, 8, 10, and 12 lines per symbol height. No significant differences between the two fonts were found. However, the analysis did indicate a significant difference due to symbol resolution. Shurfleff and Owen concluded that there was no advantage in using the Courtney font.

Review of additional research conducted on CRT type displays leads to the conclusion that no font has been shown to be more legible than others. Indeed, visual inspection of the Leroy (Figure 12) and MIL-N-18012 (Figure 19) fonts, which were most often evaluated, indicates that they are highly similar to one another.

Figure 18. Courtney alphanumerics.

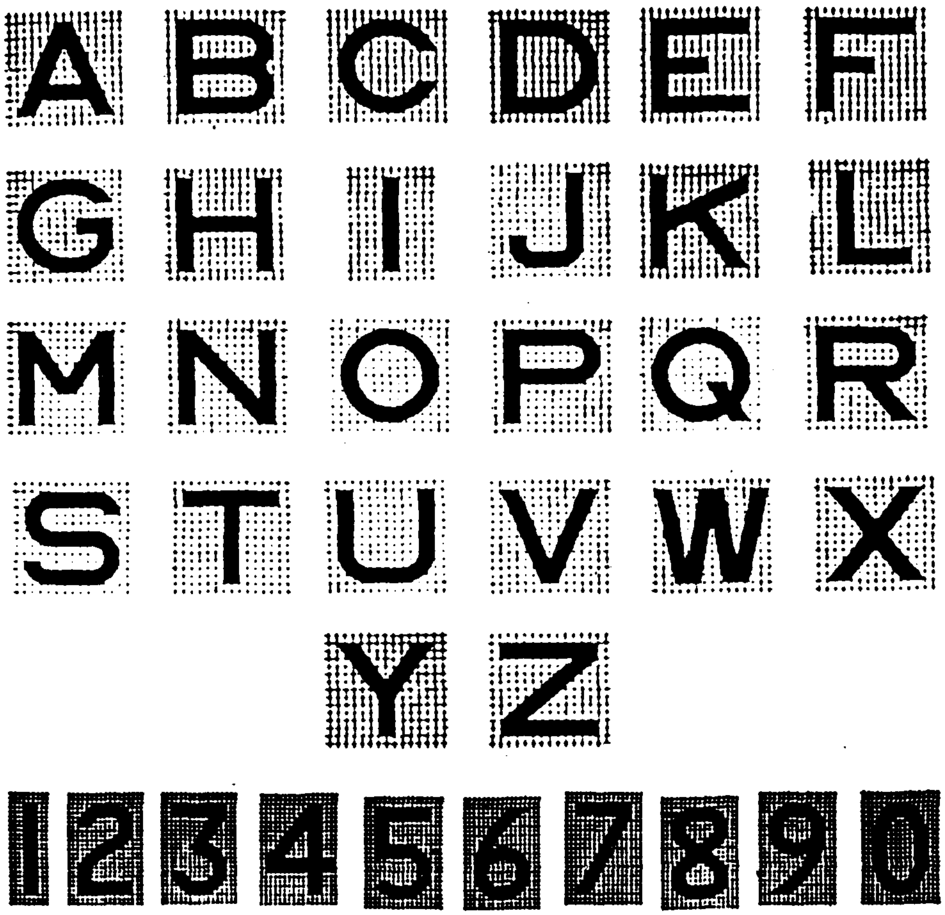


Figure 19. MIL-N-18012 (NAMEL) letters and numerals.

Relatively little research in symbol legibility using dot matrix displays has been conducted. One early study of this type compared the IBM 029, HAZELTINE, Diamond Ordnance Fuse Laboratory, and Lincoln/Mitre styles (see Figure 20) using a 5x7 dot font (Shurfleff, 1970). Comparisons of rate of symbol identification indicated that no symbol set was superior to any other.

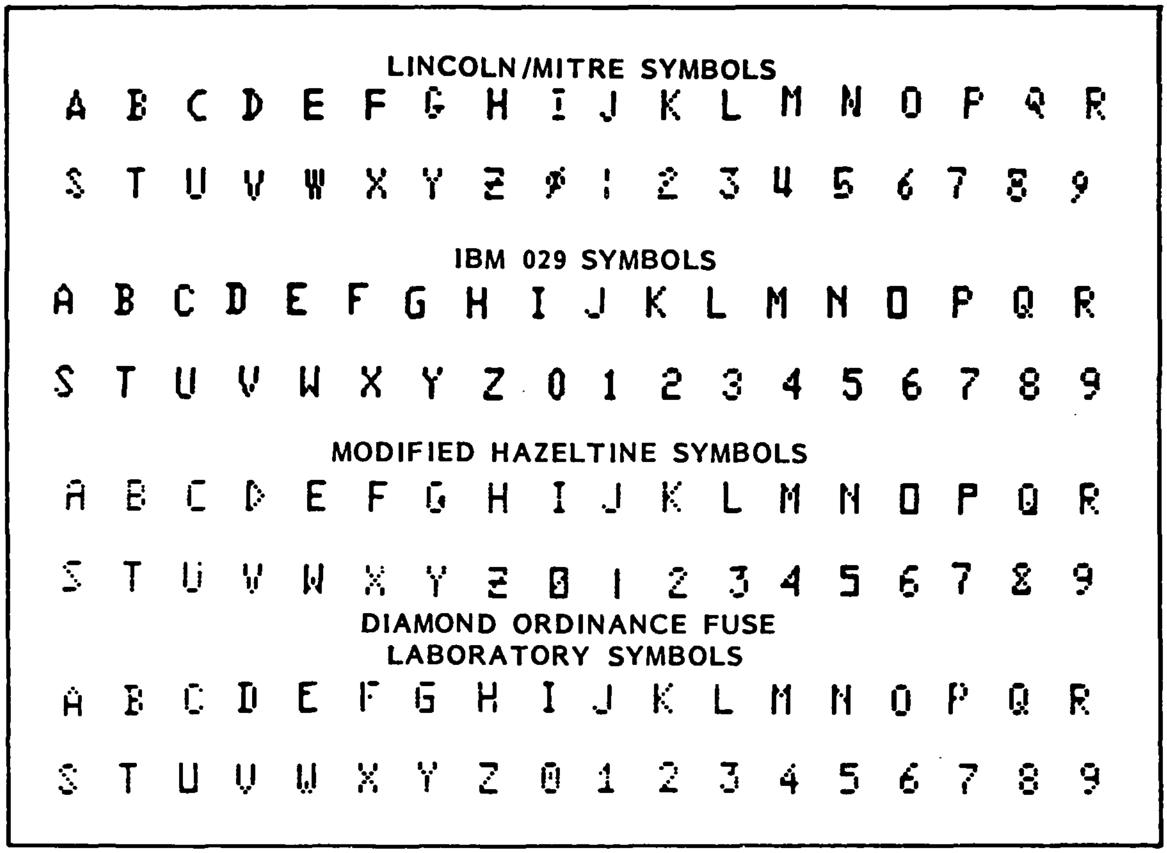


Figure 20. The four 5x7 fonts used by Shurtless (1970).

Vanderkolk et al. (1975) noted that the legibility of a font that has been originally designed for hard copy display depends on the way in which it is adapted for dot matrix display. The adaptation from hard copy to dot matrix is, in turn, influenced by matrix size, matrix shape, and arrangement of the matrix emitters. These investigators concluded that adaptations of the Lincoln/Mitre, Leroy, MIL-N-18012 (NAMEL), IBM 029, modified Hazeltine, and Diamond Ordnance Fuse Laboratory fonts could all provide good legibility of symbols with dot matrix displays.

Maddox, Burnette, and Gutmann (1977) compared Maximum Dot (Figure 21), Maximum Angle (Figure 22), and Lincoln Mitre (Figure 23) fonts using a 5x7 dot matrix. The Maximum Dot font was constructed to maximize the number of dots in a 5x7 field, resulting in a "squared-off" appearance. The Maximum Angle font was constructed to minimize the number of dots, resulting in a rather angular appearance. Identification accuracy was found to be superior for the Maximum Dot font, with errors averaging 15.2%. Identification errors for both the Lincoln/Mitre (18.2%) and the Maximum Angle (17.6%) were significantly more frequent than for the Maximum Dot.

In a more extensive evaluation of the Maximum Dot and Maximum Angle fonts, Snyder and Maddox (1978) compared these two fonts with the Lincoln/Mitre and Huddleston font (Figure 24). The Huddleston font was designed in an attempt to maximize legibility under high ambient illumination. Matrices of 5x7, 7x9, and 9x11 of different sizes, as well as dot matrices of 7x9 and 9x11 of equal size to the 5x7 matrix were used. Identification errors, averaged across all dot matrix and character sizes, were equivalent for the Lincoln/Mitre and Huddleston fonts, both of which were found to be more accurately identified than the Maximum Dot and Maximum Angle fonts. At the 5x7 dot matrix size, the Huddleston font was more accurately identified than the other three fonts. With respect to size, the 5x7 dot matrix characters were identified less accurately than the larger 7x9 and 9x11 dot matrices. However, the 7x9 and 9x11 dot matrices reduced to the size of the 5x7 dot matrix were identified more accurately than their larger counter-parts, which suggests that compactness of display generation improves legibility.

The few studies comparing fonts for dot matrix display do not support any strong recommendations for adopting a specific font. Shurtleff (1970) found no significant differences in legibility between the four fonts he compared; and the results of Maddox et al. (1977) and Snyder and Maddox (1978) are contradictory. Additionally, the exposure durations used by Maddox et al., and Snyder and Maddox may limit the applicability of these findings to the legibility of alphanumerics that are displayed for extremely brief intervals.

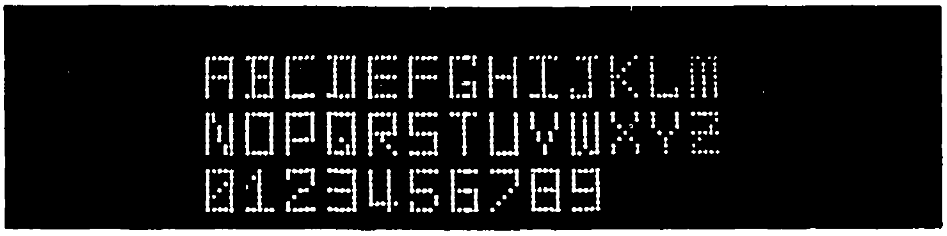


Figure 21. **Maximum dot 5x7 dot matrix used by Maddox et al. (1977).**

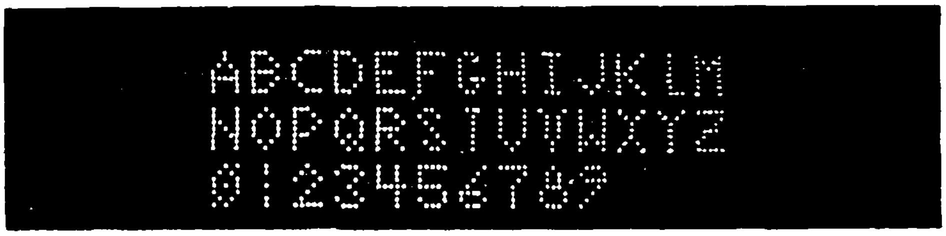


Figure 22. Maximum angle 5x7 dot matrix used by Maddox et al. (1977).

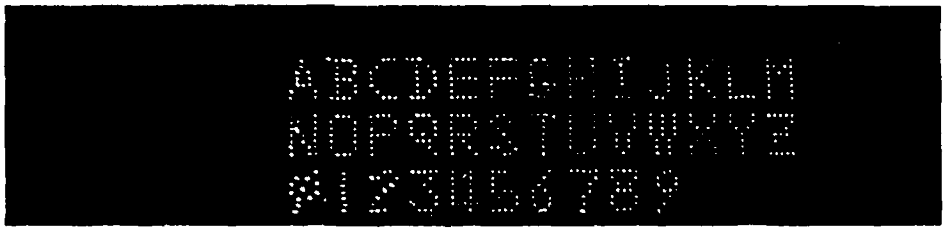


Figure 23. Lincoln/Mitre 5x7 dot matrix used by Maddox et al. (1977).

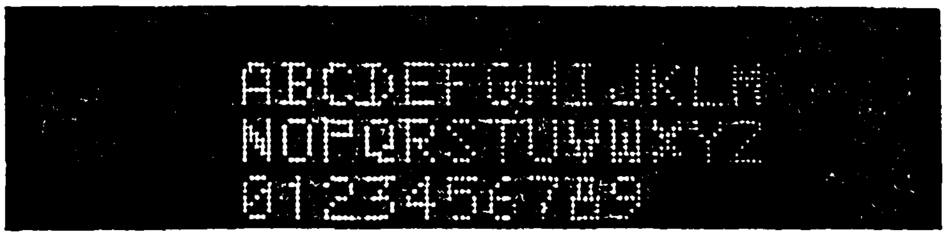


Figure 24. Huddelston 5x7 dot matrix used by Snyder and Maddox (1978).

SECTION 4
SIZE CODING

DEFINITION

Differences in the size of symbols displayed on a two-dimensional surface are usually employed to convey quantitative information related to some aspect of the information being displayed. All three types of symbols (i.e., point, line, and area) can be varied by manipulating size. Unless some legend or scale is included in a display, observers tend to discriminate between objects on the basis of their relative, rather than absolute size. When size coding depends upon relative judgments the method is more appropriately termed "proportional size coding."

Size-coded Point Symbols

Symbols of any shape can be varied in their size to code quantitative information. FM 21-31 suggests the use of absolute size coding when it prescribes that the size of the circular symbol used to represent storage tanks should be scaled to the size of the actual tank when large tanks are depicted on large-scale maps. Proportional size coding can be used with sets of geometric shapes of graduated sizes. The use of graduated circles to represent towns with different populations on small-scale roadmaps is probably the most common example of point symbols that are coded via proportional size coding.

Size-coded Line Symbols

Size coding of straight, continuous lines is often achieved by varying the width of the line. Line symbols constructed with the use of separate segments can vary in either the height of the segments or the length of the segments. The latter variation is commonly seen on maps where dashed lines of different length are used to depict borders of different types.

Size-coded Area Symbols

Size coding can be employed with area symbols by varying the size of point or line symbols that fill an area.

IMPORTANT ISSUES IN SIZE CODING

The ability of people to determine the absolute size of symbols by visual inspection is very limited. The accuracy of observers in discriminating a difference between symbols with a constant difference in size varies systematically with the absolute size of the symbols. Therefore, both the number of size increments and the amount of information that can be conveyed on the basis of size differences is rather limited. However, size coding has been shown to be useful for certain applications. If this dimension is to be used in a symbology system, selection of a set of symbol sizes requires consideration of the incremental differences in symbol size, the type of decision task required of the observer, and the amount of additional size information that is presented to the observer.

GENERAL CONCLUSIONS

Research has been conducted on the recommended size increments between symbols, the interrelationship between task type and symbol size, and the type of observer task most compatible with size coding. Some general conclusions follow.

- The method of equal ratio scaling can be used to designate a set of symbols varying in size that are optimally discriminable from one another.
- The useful number of size-coded symbols can be increased by including a legend showing all symbol sizes.
- For simple geometric point symbols, a maximum of five different sizes can be absolutely identified without the aid of a legend; recommendations for operational conditions commonly set three different sizes as the maximum.
- Proportional differences in symbol size are best used to convey differences in the relative size of objects referred to by symbols.
- Research in size coding has been limited to simple geometric shapes presented via hard copy and CRT displays. The use of other types of symbols or displays would require further research.

APPLICABLE RESEARCH

Research applicable to specifying size code alphabets that maximize symbol identification has dealt almost exclusively with the coding of point symbols. Grether and Baker (1972) report a study they conducted (Baker & Grether, 1954) to assess accuracy in identifying symbols on the basis of size. The symbols varied in size on the basis of a logarithmic relationship. That is, the area of each symbol could be specified by a constant ratio of the preceding symbol area. Figure 25 presents the data obtained by Baker and Grether. Inspection of this figure

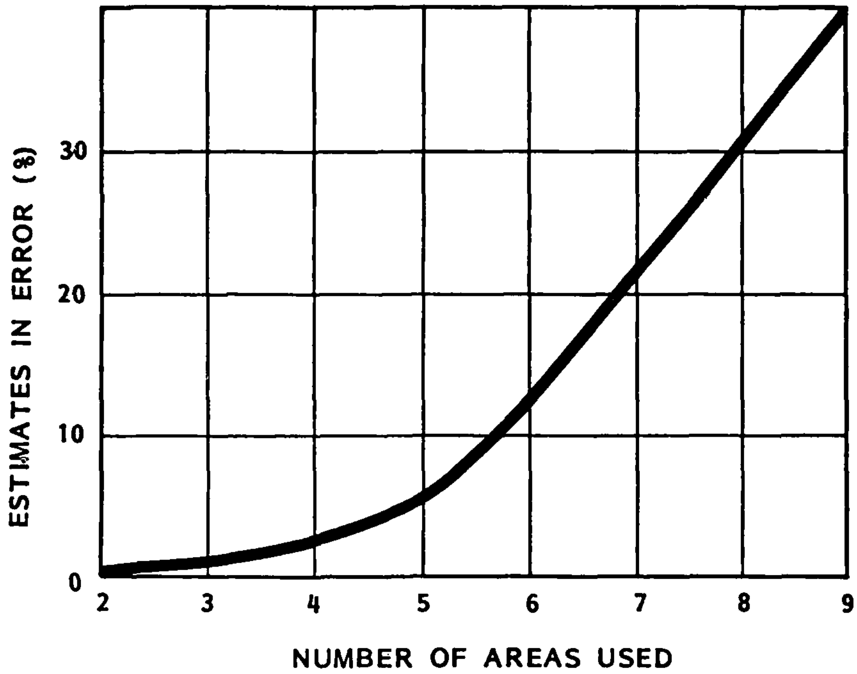


Figure 25. Results of Baker and Grether's (1954) study comparing absolute identification accuracy of area magnitude with different numbers of area codes. For each area alphabet, equal ratio scaling of area was used. (Adapted from Grether and Baker, 1972.)

indicates a rapid increase in identification errors when the number of different symbols exceeded five.

Muller, Sidorsky, Slivinske, and Alluisi (1955) used a modified method of equal ratio scaling to derive three-, four-, and five-step codes. The alphabets derived from this scaling research represented a slight modification of the constant ratio technique used by Baker and Grether (1954) to allow for scale end-point, or anchor, effects. Accuracy of observers in discriminating between the dot symbols from the three sets was better than 99% for the three-dot set, better than 98% for the four-dot set, and better than 95% for the five-dot set.

The common guideline for maximizing the identifiability of symbol size is to use a logarithmic scale of symbol area for all set members (Grether & Baker, 1972; Potash, 1977). Specifically, Grether and Baker recommend a constant ratio of 3.2. Adopting this rule for a set of five sizes beginning at .01 inch square results in a set with .01, .032, .10, and .32, and 1.0 inch square. Recommendations concerning the number of different sizes that should be used commonly state five as the maximum and two or three as a safe upper limit for operational conditions (Barmack & Sinaiko, 1966; Grether & Baker, 1972; Meister & Sullivan, 1969; Woodson, 1981). It is important to note that all of the research and recommendations concerned with size alphabets have used simple two-dimensional forms, such as circles and squares. The use of other shape symbols in a size alphabet would require direct experimentation. Additionally, the problem of display resolution must be considered in the design of a size alphabet. Even though optimum increments for dot size identification have been determined experimentally for hard-copy and video CRT type displays, the resolution of pixel matrix displays would require further research.

A set of symbols varying in size can be used to code numerous types of information. However, the most common use is to code quantitative information, particularly the size of the object depicted by the symbol. The recommendations for limiting a size code alphabet to between two and five sizes, using a ratio scale, suggests that relative, rather than absolute, size is best conveyed by gradations in point symbol size. Comprehension of relative size (i.e., "small," "medium," and "large,") should be somewhat easier than identification of non-quantitative codes assigned to differences in size, although such observer tasks have not been studied in this context. The use of symbol size for coding more precise quantiative information, however, would likely require either more extensive training or the use of a symbol index (cf. Meihoeffer, 1973).

SECTION 5
NUMEROSITY CODING

DEFINITION

Numerosity refers to the number of items displayed. Numerosity of individual symbols can be used to code information about either the specific number or the density of features. Density coding is employed when the relative frequency of units within a standard area, rather than the absolute number, is intended to be the major basis for discriminating between symbols.

Numerosity-coded Point and Line Symbols

The number of specific forms, such as dots, used to modify a complex point symbol can be used to indicate a relative or absolute quantitative value associated with that symbol. For example, FM 21-30 prescribes the use of this method to depict the echelon of military units, as shown in Figure 26.

U.S. DESCRIPTION	SYMBOL
Squad	●
Section or unit larger than a squad but smaller than a platoon	● ●
Platoon or detachment	●●●
Company, battery or troop	I
Battalion or squadron	II
Group or regiment	III
Brigade or equivalent command	X
Division	XX
Corps	XXX
Army	XXXX
Army group	XXXXX

Figure 26. Numerosity coding prescribed in FM 21-30.

The use of numerosity coding in line symbols is commonly restricted to the use of between one and three parallel lines to represent some aspect of a boundary, road, or canal.

Numerosity-coded Area Symbols

Numerosity coding can also be used to convey information about the actual numbers of items in an area through the repetition of point symbols, as shown in Figure 27. This application of numerosity coding, referred to as the "statistical-pictorial principle" by Arnberger (1974), is often used in conjunction with a legend explaining the number of units represented by individual point symbols.

Probably the most basic use of density coding of areas involves variation in the density of dots filling an area which, in turn, results in variations in the shading of those areas. Another use of density coding is represented by contour lines used to code relief information on topographic maps. Contour lines are most appropriately classified as based upon the dimension of density, since the density of lines is designed to code information concerning the slope of terrain. Figure 28 shows a contour-line depiction of various landforms.

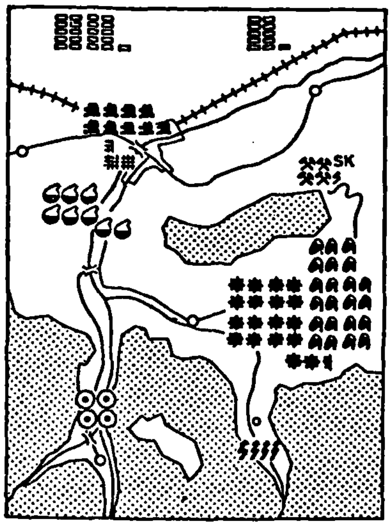


Figure 27. An example of numerosity coding used with area symbols. (Adapted from Arnberger, 1974.)

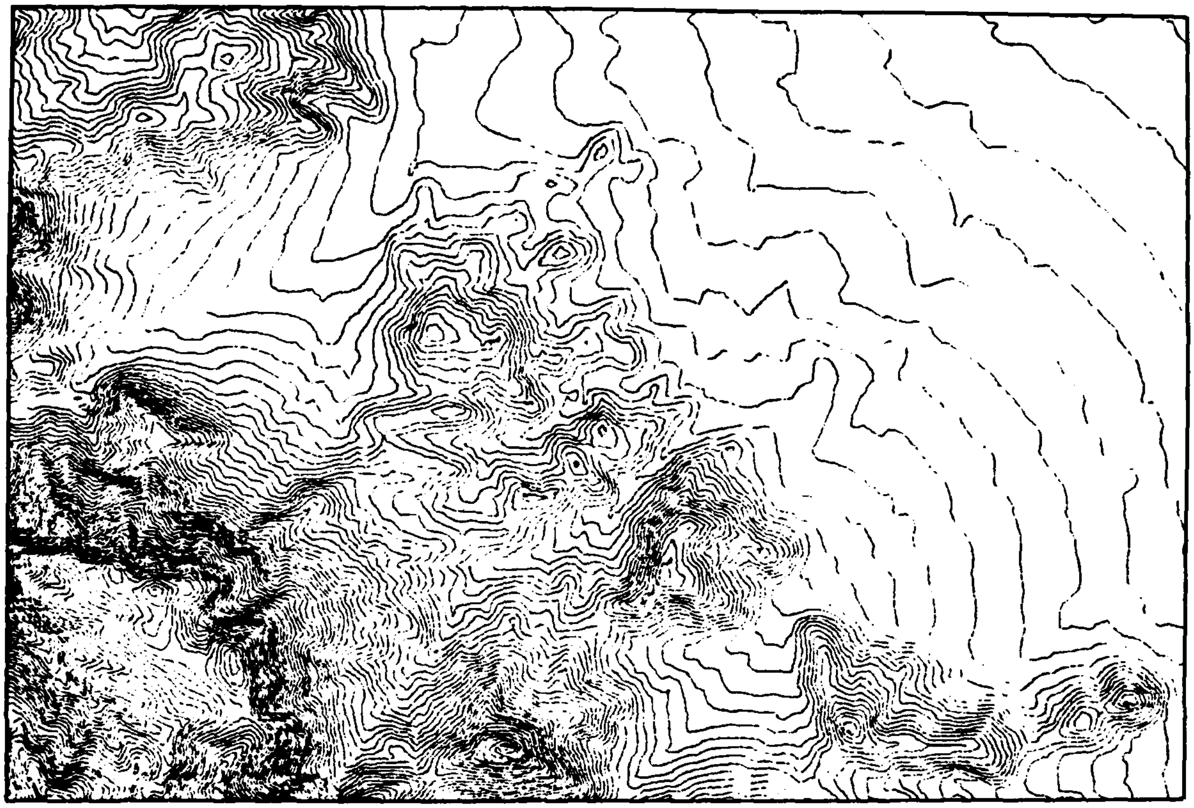


Figure 28. An example of contour-line depiction of landforms.

IMPORTANT ISSUES IN NUMEROSITY CODING

Three basic methods of numerosity coding have been defined above: absolute number, dot density, and line density. Absolute number coding is used when the observer is required to identify the number of symbols. The primary issue in using this method of coding is the maximum number of dots that can be accurately reported. When dot density is used as a coding technique, the task of the observer is to be able to discriminate between or identify different densities. So, an important issue is the difference in density required for accurate identification of different densities. Line density can be used for two purposes. It can be used to code differences in area via shading, which requires consideration of the same basic issues as dot density, or it can be used for contour coding.

GENERAL CONCLUSIONS

Research applicable to numerosity coding was only found for tasks requiring observers to report the absolute or estimated number of dots. The following conclusions can be drawn from this research.

- Five or six point symbols arranged compactly is the maximum number of items that can be identified accurately by most observers following a brief presentation.
- The maximum number of items that can be identified accurately increases with the duration of presentation or the consistency of time arrangement.
- The perception of equal increments in dot density, or estimated dot number, is best described by a constant ratio function.

No research applicable to line density was found in the literature. Research in this area would be required prior to implementing this method if more than two or three levels of density were to be identified absolutely.

APPLICABLE RESEARCH

The number of separate symbols that can be accurately apprehended following a brief presentation sets the limit in size of an "absolute number" alphabet. Alphabets for density coding are based upon the psychophysical relationship between presented and estimated number. Each of these types of alphabets will be discussed separately below.

Early research in absolute number identification was viewed as a means of estimating the "span of attention," which was commonly defined as the number of discrete objects that can be apprehended simultaneously. Several early studies (i.e., Fernberger, 1921; Glanville & Dallenbach, 1920; Oberly, 1924) demonstrated that when subjects were required to correctly report the number of black dots on a white card exposed foveally for appoximately .10 second, five dots could be reported with approximately 98% accuracy across all subjects. Errors increased substantially for some subjects when more than five dots were presented; whereas other subjects were still accurate when as many as eight dots were presented.

Later work by Kaufman, Lord, Reese, and Volkmann (1949) investigated the apparent difference in subjects' performance when the number of dots exceeded their capability to correctly report visual number. In this study, random patterns of dots were presented to subjects for .20 second. The number of dots in each pattern varied from 1 to more than 200. Subjects made no errors in reporting the number of dots presented when patterns contained up to five or six dots; however, errors increased markedly beyond this point. Kaufman et al., termed the task one of **subitizing** the pattern when it contained seven dots or less, and **estimating** the number of dots when the number exceeded seven.

The research with dots in random locations suggests that a maximum of five or six simple point symbols should be used to code information related to specific number if symbols are placed in a random position and viewed foveally for brief periods. This research also indicates that both longer exposure durations and the use of standard configurations for each number could lead to better accuracy (Oberly, 1924). When additional numbers of randomly arranged symbols are presented for longer durations, the observer's task is reduced to one of counting, which requires an amount of time that is proportional to the number of dots displayed (Jensen, Reese, & Reese, 1950). The use of standard configurations represents a method of shape coding, rather than numerosity coding.

Taves (1941) investigated the process of visual number estimation and found that a constant ratio, or logarithmic, function best describes estimated density. Such a function should be used to specify density codes based on dots to optimize discriminability between alphabet members which, in turn, would optimize the identification of different densities.

No research applicable to different spacing schemes for line density was found in the literature. However, if the finding with dot density coding represents a more general perceptual phenomenon, it is likely that the perception of equally discriminable densities of lines also follows a constant ratio function. However, this possibility would require objective assessment.

SECTION 6
INCLINATION CODING

DEFINITION

Inclination coding uses the orientation of a symbol to convey information. The most common method of inclination coding involves rotation with respect to the fontal plane of observation. However, the phenomenon of object constancy allows the coding of apparent rotation of symbols about axes other than the frontal plane.

Inclination-coded Point Symbols

Frontal plane rotation of point symbols is commonly employed with some constant reference shape to indicate variation in inclination or one or more lines within the shape (such as a clock face). This method is referred to as lineal inclination coding. Only in the case of point symbols can symbols appear to rotate about axes other than the frontal plane. For example, circular symbols can be rotated in non-frontal planes, resulting in elliptical symbols.

Inclincation-coded Line and Area Symbols

The use of inclination coding with line and area symbols is usually restricted to the frontal plane inclination of parallel lines filling a border or area. This method of coding can also be used with outlined point symbols.

IMPORTANT ISSUES

The fundamental issue in considering inclination coding is the accuracy with which observers can judge the degree of symbol or lineal inclination. There is, of course, some limit in this degree of accuracy. However, it may be the case that certain inclinations are more accurately judged by observers. The accuracy of absolute judgment, or symbol identification, determines the number of inclinations that can be used in an inclination alphabet. If some inclinations are more accurately identified than others, an inclination alphabet with the maximum number of identifiable symbols would not consist of inclinations equally spaced throughout 360° of rotation. Another issue concerns the use of inclination coding with dot and pixel matrix displays, where degradations in symbol legibility may result from rotation.

GENERAL CONCLUSIONS

The utility of lineal inclination for coding information on CRT displays was studied by Muller, Sidorsky, and Slivinsky (1955) and later by Alluisi (1961). Other types of inclination coding have not been systematically investigated. The research in this area suggest the following conclusions.

- Four natural anchor points are used by most observers in judging the degree of lineal inclination. Errors in judgment systematically increase as the lineal inclination of symbols diverge from these four anchor points.
- Accuracy in identifying a set of 24 different inclination codes has been shown to be 97% after moderate practice.
- Subjects are more accurate at identifying lineal inclination codes on the basis of assigned ordinal number than on the basis of degree of rotation.
- Research in symbol legibility suggests that inclination coding cannot be readily adapted to the use of small symbols on a dot matrix display; although further research in this area is required.

The utility of coding information by rotating forms about axes other than the frontal plane requires further research. The maximum size of inclination-coded line and area symbol alphabets has not been empirically determined.

APPLICABLE RESEARCH

Initial research in specifying equally discriminable steps that could be used for lineal inclination coding was reported by Muller et al. (1955). These researchers found that subjects made very few errors in identifying inclinations of 0°, 90°, 180°, and 270°. Errors in identification tended to increase as the degree of inclination from these four meridians increased. The findings suggest that the four meridians serve as natural anchor points for judgment by observers.

Alluisi (1961) reported a series of experiments designed to establish and validate four lineal inclination code alphabets. In the first study, the method of equal-discriminability scaling of absolute judgments, developed by Garner and Hake (1951), was used to identify possible alphabets. Eighty different inclinations were used in the study based upon the previous research of Muller et al. (1955). Stimuli were identified on the basis of a preassigned quadrant and number. An information analysis (cf., Garner & Hake, 1951) of subjects' identifications indicated that only 12 different inclinations could be absolutely identified in this first study reported by Alluisi (1961). However, previous research by Muller et al. (1955) had demonstrated that as many as 25 inclinations could be identified by practiced observers. Thus it seemed necessary to construct and assess identification accuracy of inclination alphabets varying in size rather than to rely upon an information analysis.

Alluisi and his colleagues used the results from their first study to construct four inclination alphabets consisting of 12, 16, 20, and 24 symbols (see Figure 29). The practical value of the four inclination alphabets is best evaluated on the basis of errors in identifying the symbols from each alphabet. Table 7 presents the percentage of identification errors made during the practice and performance sessions of the study for each alphabet. As can be seen, identification accuracy after this moderate level of training was above 99.8% for the 12- and 16-symbol alphabets, above 98% for the 20-symbol alphabet, and above 97% for the 24-symbol alphabet.

Alluisi (1961) suggested that any of the four inclination alphabets could be used for the purposes of symbol coding. In addition, Alluisi found that subjects could more accurately identify the symbols from larger sets by using the "readout" terms rather than using the "inclination" terms specified in Figure 29. Highly accurate identification of the actual quantitative inclination was only found with alphabets consisting of 12 or fewer symbols.

Research in scaling lineal inclination alphabets with two pointers and ellipse-axis alphabets has been conducted by Muller et al. (1955). However, this work was not followed by validation research to establish alphabets with a maximum number of symbols. Alluisi and Muller (1958) conducted research in the identification of the four 10-symbol alphabets shown in Figure 30, however their method of forced-paced symbol presentation restricts the application of their findings. Identification accuracy in this study was better than 97% and 99% for the binary inclination and ellipse-axis ratio alphabets, respectively. Thus, for 10-symbol alphabets, both of these methods result in high levels of identification accuracy when identification is performed at a forced pace.

12-SYMBOL ALPHABET

Symbol:						
Inclination:	0°	16°	74°	90°	106°	164°
Readout:	A-0	A-1	A-2	B-0	B-1	B-2
Symbol:						
Inclination:	180°	196°	254°	270°	286°	344°
Readout:	C-0	C-1	C-2	D-0	D-1	D-2

20-SYMBOL ALPHABET

Symbol:					
Inclination:	0°	8°	23°	67°	82°
Readout:	A-0	A-1	A-2	A-3	A-4
Symbol:					
Inclination:	90°	98°	113°	157°	172°
Readout:	B-0	B-1	B-2	B-3	B-4
Symbol:					
Inclination:	180°	188°	203°	247°	262°
Readout:	C-0	C-1	C-2	C-3	C-4
Symbol:					
Inclination:	270°	278°	293°	337°	352°
Readout:	D-0	D-1	D-2	D-3	D-4

24-SYMBOL ALPHABET

Symbol:						
Inclination:	0°	6°	16°	45°	74°	84°
Readout:	A-0	A-1	A-2	A-3	A-4	A-5
Symbol:						
Inclination:	90°	96°	106°	135°	164°	174°
Readout:	B-0	B-1	B-2	B-3	B-4	B-5
Symbol:						
Inclination:	180°	186°	196°	225°	254°	264°
Readout:	C-0	C-1	C-2	C-3	C-4	C-5
Symbol:						
Inclination:	270°	276°	286°	315°	344°	354°
Readout:	D-0	D-1	D-2	D-3	D-4	D-5

16-SYMBOL ALPHABET

Symbol:								
Inclination:	0°	10°	45°	80°	90°	100°	135°	170°
Readout:	A-0	A-1	A-2	A-3	B-0	B-1	B-2	B-3
Symbol:								
Inclination:	180°	190°	225°	260°	270°	280°	315°	350°
Readout:	C-0	C-1	C-2	C-3	D-0	D-1	D-2	D-3

Figure 29. Four inclination alphabets used by Alluisi (1961).

TABLE 7

IDENTIFICATION ERROR (PERCENT) FOR THE FOUR INCLINATION ALPHABETS DURING PRACTICE AND PERFORMANCE SESSIONS (Alluisi, 1961)

Alphabet (Number of Symbols)	Practice Sessions (1-4)	Performance Sessions (5-8)
12	0.434	0.174
16	0.868	0.174
20	3.661	1.562
24	5.686	2.257

Although the research conducted by Muller et al. (1955) and Alluisi (1961) was directed towards electronic display applications, both studies used hard copy photographs as experimental materials. Applicability of these data to either dot matrix or pixel matrix displays is unclear. Furthermore, it is necessary to consider the legibility of rotated symbols. Vanderkolk et al. (1975) observed a decrease in the legibility of alphanumerics on a pixel display with inclinations of 15^{o}. However this research concerns the legibility of a shape, rather than a line. Further research with lineal inclination codes using dot matrix and pixel displays is necessary before operational implementation.

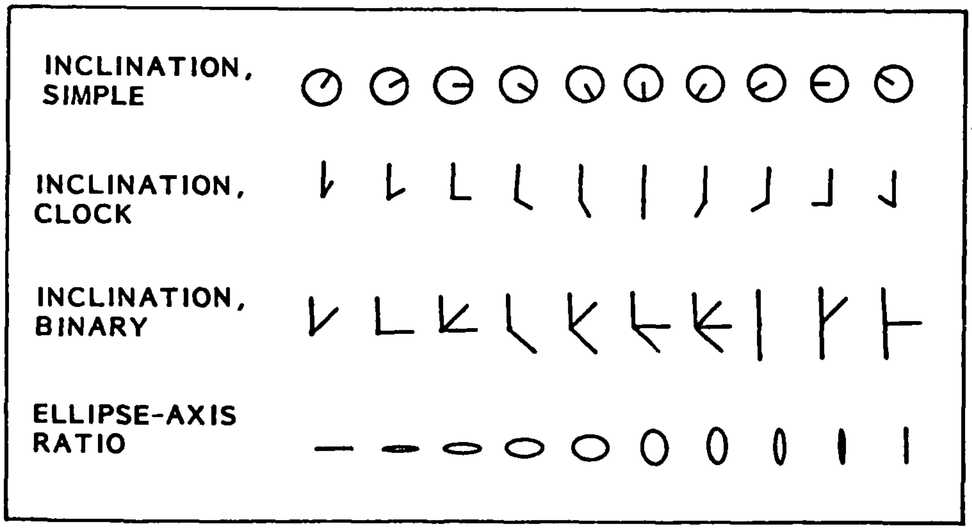


Figure 30. Inclination alphabets used by Alluisi and Muller (1958). (Adapted from Alluisi and Muller, 1958.)

SECTION 7
BRIGHTNESS CODING

DEFINITION

The term brightness is used to refer to the perceived intensity of achromatic light, or shades of gray, when unidimensional coding is considered. For luminous displays, perceived brightness is related to the luminosity of the symbol, although levels of ambient light also affect perceived brightness (Grether & Baker, 1972).

Brightness-coded Point and Line Symbols

Brightness coding of point and line symbols is limited to the use of brightness levels that can be easily discriminated and identified by an observer.

Brightness-coded Area Symbols

Entire areas can be presented in different levels of brightness. Absolutely identifiable levels can be used in this application, just as with point and line symbols. However, brightness levels of adjacent sections within an area need not be absolutely identifiable if observers can discriminate differences between the adjacent levels. In this second use of brightness coding, comparative, rather than absolute, judgments are required; and several more levels of brightness can be used.

IMPORTANT ISSUES IN BRIGHTNESS CODING

Three important issues must be considered when designing a symbology system using brightness coding. First, it is important to determine whether absolute identification of brightness levels or comparative judgments between different levels of brightness will be required of an observer. Second, the number of steps and the spacing of these steps along the brightness dimension must be determined. Finally, the ambient and background light conditions in the operational setting must be considered when using brightness coding.

GENERAL CONCLUSIONS

A brief review of applicable research suggests the following general conclusions.

- Relatively few steps are recommended for brightness-coding with point and line symbols if absolute identification is required of the observer. Five or six levels of brightness have been suggested as the maximum under optimal display conditions. Three steps of brightness is the probable limit in operational settings where ambient light and background illumination vary.

- Constant ratio scaling of brightness increments can be used for selecting a prelimininary set of graduated levels of brightness for use in area coding when judgments are comparative.

- If ambient light in the operational environment is expected to vary, research may be required to define optimal display brightness levels.

APPLICABLE RESEARCH

Basic psychophysical research in the discrimination of brightness levels is directly applicable to the selection of brightness codes. Existing data can be used to specify alternative levels of brightness that are likely to be identified on an absolute basis. In addition, the findings can be used to specify optimal increments in brightness for the coding of adjacent areas so that they are perceived to vary in equally graduated increments. Therefore, a brief discussion of research applicable to the psychophysical scaling of brightness will precede a review of research directed towards establishing a brightness alphabet that can be identified absolutely by observers.

Hanes (1949a, 1949b) used the halving technique to determine the psychophysical relationship between perceived brightness and a measure of light energy (photons) that takes into consideration the size of the pupil. In the two studies, subjects adjusted a patch of light until it was perceived to be half as bright as it had been initially. Hanes found that a logrithmic function best described the relationship between the perceived magnitude of brightness and the amount of light entering the pupil. So, just as in the case of perceived size, successively greater changes in the physical magnitude of a light stimulis are required for equally discriminable differences in brightness to be perceived. Within the range of day vision, the research of Stevens and Stevens (1963) in magnitude estimation suggests that increases in luminance (measured in dB) must increase exponentially (at approximately the third power) to result in a linear increase in perceived brilliance of a single light source. Munsell gray scales have been shown to be a relatively useful set of brightness stimuli representing equally discriminable steps (Newhall, 1950).

All applications of a brightness scale are not as straightforward as the preceding discussion implies. It has been demonstrated that the perception of brightness is influenced by both background illumination (e.g., Mueller, 1951) and the luminance of a surround field within the background (e.g., Heinemann, 1955). If brightness coding for either absolute identification or comparative judgment is to be used in environments where either background or surround luminance levels vary, additional research should be conducted. Use of the Munsell gray scale or Stevens and Stevens' (1963) power function should lead to a good first approximation in selecting appropriate brightness levels.

Under ideal circumstances, it is possible that a viewer might be able to discriminate about 40 shades of gray on a CRT (Volkoff, 1971). Under conditions experienced by Army aviators, however, it is unlikely that more than about eight shades of gray could be discriminated (Slocum, 1974), although if a very bright CRT (about 4,000 fL) were used with filtering and hooding of the display surface, as many as 14 gray shades could possibly be discriminated.

A study relevant to the construction of a brightness alphabet for absolute identification tasks was conducted by Ericksen and Hake (1955). They estimated that the maximum number of different brightness stimuli is approximately five with moderate amounts of practice and six following extensive training. Human factors guidelines (i.e., Grether & Baker, 1972; Woodson, 1981) set a maximum of two values of brightness coding in the operational setting, due to changes in ambient light and interference between brightness codes and other codes. However, the limit of two levels is not supported by empirical research, which is lacking in this area. Bishop and Crook (1961) report "satisfactory" identification accuracy of three luminance levels of 1, 10, and 100 fL in the context of a color code identification study. Conover and Kraft (1954) estimated that the average person's ability to reliably identify brightness steps is limited to not more than three steps: white, gray, and black. Implementation of an alphabet larger than three would require further empirical research.

SECTION 8
COLOR CODING

DEFINITION

The three psychological attributes of color are hue, saturation, and brightness. These attributes (diagramatically represented in Figure 31) are the response correlates of dominant wavelength, purity of the spectral composition, and luminance. Such a system for specifying color is necessary, since the perception of displayed color varies for different values of these three stimulus characteristics.

In selecting colors to be used for symbol coding, it is important to consider existing color alphabets. The prescribed use of color for point, line, and area symbols in FM 21-30 and FM 21-31 will be briefly reviewed, since these standards will impact the use of color in any symbology system adapted for military purposes.

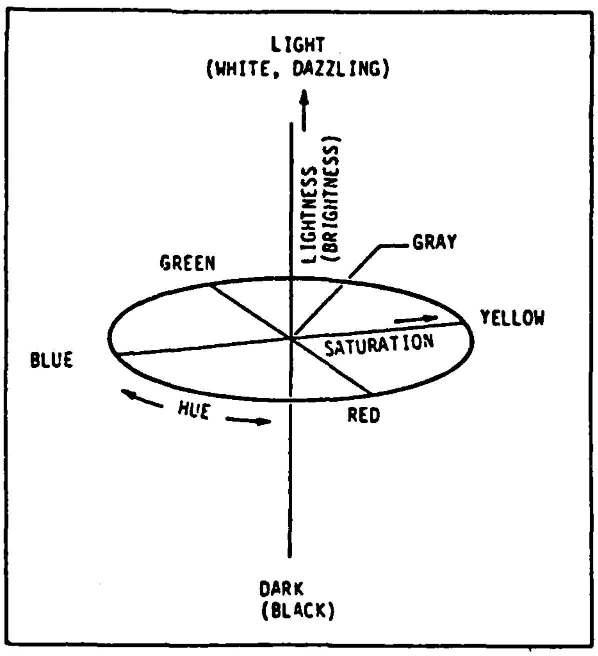


Figure 31. The three subjective dimensions of color.

Color-coded Point Symbols

The color codes prescribed in FM 21-30 and FM 21-31 for point symbols are listed below.

FM 21-30 specifies the use of three colors for the coding of point symbols.

- Blue or black for friendly units, installations, equipments, and activities.
- Red for enemy units, installations, equipments, and activities.
- Green for friendly or enemy man-made obstacles.

FM 21-31 specifies the use of two colors in the coding of point symbols.

- Purple for aerodromes, seaplane bases, heliports, and range references.
- Red for route markers and all buildings.

Color-coded Line Symbols

FM 21-30 does not specify the use of any color for the coding of line symbols. FM 21-31 specifies four colors for this purpose.

- Blue for streams, rivers, and canals.
- Red for main roads, power lines, telegraph and telephone lines, and international boundaries.
- Black for secondary roads.
- Purple for magnetic variation lines (isogonic lines).

Color-coded Area Symbols

FM 21-30 specifies the use of yellow to code areas of chemical, biological, or radiological contamination. FM 21-31 specifies the use of five colors in area coding.

- Blue for swamps, lakes, and coastal waters.
- Green for vegetation such as woods, orchards, and vineyards.
- Brown for all relief features, such as contour lines.
- Red for inhabitated, built-up areas such as cities, town, and native settlements.
- Purple for air defense identification zones and military buffer zones.

IMPORTANT ISSUES IN COLOR CODING

In establishing a useful color alphabet, it is important to determine whether surface color or colored light is to be used, since colors are specified differently with each mode of display and certain factors, such as colored ambient illumination, differentially affect color perception in each mode. The present discussion focuses on colored light, which is most applicable for electronic displays. The primary issue in this discussion is the maximum size of a color alphabet that can be identified by observers without additional aids or legends. However, since color is defined on the basis of hue, brightness, and saturation, it is important to determine whether hue alone, or a combination of these component attributes are to be varied in a coding alphabet.

GENERAL CONCLUSIONS

A review of applicable research in color coding suggests the following general conclusions concerning the use of colored light for coding.

- If the dimensions of a colored symbol subtend more than approximately 15 minutes of visual arc, properties of symbols other than hue, saturation, and brightness play a minor role in color identification.
- The sensitivity of the human eye to differences in hue varies along the hue spectrum, and the selection of equally discriminable hues must be based on these sensitivity differences.
- The maximum size of a colored light hue alphabet that can be absolutely identified without extensive training is between 8 and 12 hues.
- If hue, brightness, and saturation are all varied with colored light displays, a minimum of 28 different colors can be accurately identified against a white background after a moderate amount of practice. After more extensive practice, a minimum of 28 different colors can be identified against colored backgrounds varying in saturation.

Previous research can be used to specify preliminary hue and color alphabets. However, due to the interrelatedness of the human visual process and the parameters associated with light and color display, alternative color alphabets should be validated with the system for which they are designed.

APPLICABLE RESEARCH

The colors that can be used in colored light alphabets can be specified on the basis of symbol brightness, hue, and saturation when stimulus size exceeds approximately 15 minutes of visual arc (Bishop & Crook, 1961). Additional properties, such as volume, form, and transmittance are relevant in certain applications, but they have a minor impact in most electronic display applications. Research related to the specification of identifiable colored light alphabets can be divided into work dealing with hue alone and research that includes colored stimuli varying in brightness and saturation as well. The remainder of this section presents a selective review of research related to the design of color-coded alphabets.

The physical value of hue can be defined on the basis of a linear measure of wavelength. Research by Wulfeck, Weisz, and Rabin (1958) indicates that the sensitivity of observers to small changes in hue varies at different regions along the wavelength spectrum. As depicted in Figure 32, sensitivity to differences in hue is high in the green (515 millimicrons) and yellow (580 millimicrons) portions of the spectrum, where differences as small as one millimicron can be detected. In contrast, sensitivity to differences in hue is reduced in the red end of the spectrum, where changes as great as 20 millimicrons are required before a difference in hue can be detected.

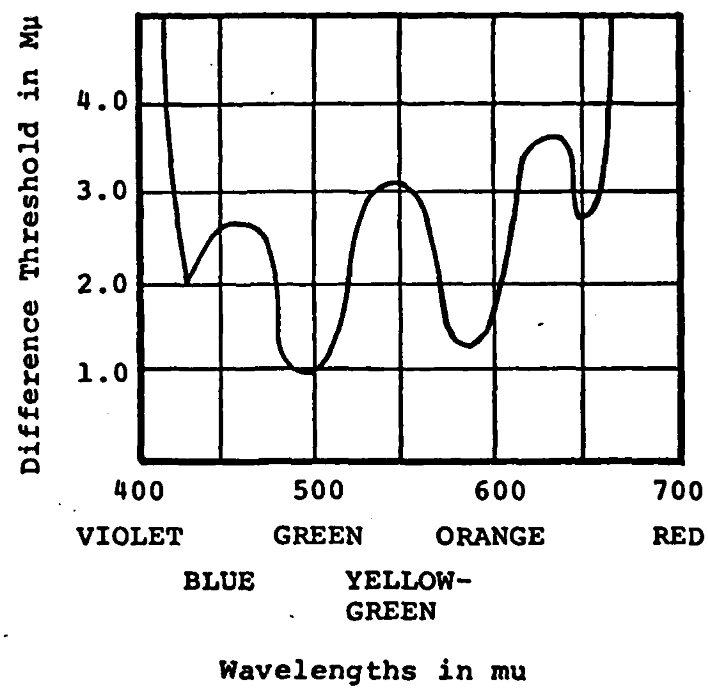


Figure 32. The smallest difference in wavelength that can be detected as different in hue using the comparative method of discrimination (from Wulfeck, Weisz, & Raben, 1958).

Variation in sensitivity to changes in wavelength across the hue spectrum is an important consideration when selecting identifiable hues for a color-coded alphabet. Halsey and Chapanis (1951) used Wright's (1947) discriminability data to select an initial set of 17 hues in their attempt to construct a hue alphabet with a maximum number of steps. The wavelengths selected for the 17-hue alphabet represented a range between 430 and 642 millimicrons. Identification accuracy with this 17-set alphabet was 72.4% following moderate practice. This level of identification accuracy led Halsey and Chapanis to make successive reductions in alphabet size in an attempt to determine a hue alphabet that could be identified with a high degree of accuracy.

Halsey and Chapanis next constructed a 15-hue alphabet, in which the two pairs of adjacent wavelengths which were most often confused in the 17-hue alphabet were replaced by two hues about midway between the members of each pair. Identification accuracy after moderate practice with the new 15-hue alphabet was 92% for one observer and 97% for another. Adjustments similar to those made for the preceding alphabet were made in the construction of a 12-hue alphabet. Average identification accuracy for four observers was 96% with this 12-hue alphabet. Finally, a 10-hue alphabet was constructed by selecting every other hue from the original 17-hue alphabet (with one exception). Identification accuracy averaged 97.5% for two observers with this set.

Grether and Baker (1972) present the final 10-hue alphabet constructed by Halsey and Chapanis (see Figure 33) as a possible alphabet to be used in applied settings. However, as Halsey and Chapanis acknowledge, "Although the 10-hue series gave the highest percentage of correct identifications, it probably does not include the maximum number of colors which are absolutely identifiable. The hues in this series were spaced arbitrarily, rather than according to the incidence of confusion." Thus, more optimal spacing or the use of more extensive practice, as noted by Chapanis and Halsey (1956), may have resulted in a larger hue-alphabet being identified with 97% or higher accuracy. Halsey and Chapanis made a final estimate that between 10 and 12 optimally spaced hues would represent the maximum size of an absolutely identifiable hue alphabet.

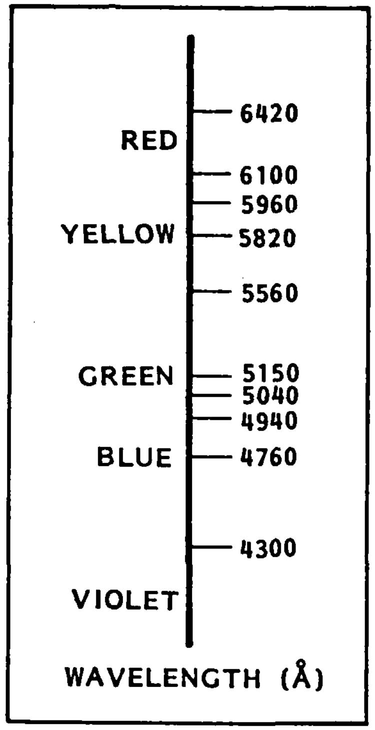


Figure 33. The 10-hue alphabet used by Halsey and Chapanis (1951).

Ericksen and Hake (1955) conducted a study using the method of absolute judgment to determine the maximum amount of information that could be conveyed by a hue alphabet. Twenty different hues of equal saturation and brightness, representing the entire range of visible hues, were selected from the Munsell scales. The analysis of judgments from six observers indicated that at least eight different hues could be absolutely identified with moderate levels of practice. This is comparable to Conover and Kraft's (1954) estimate for surface hues using a similar experimental approach. Ericksen and Hake's estimate of maximum alphabet size is markedly lower than that determined by Halsey and Chapanis (1951). However, analysis of the final identification trials after extensive practice indicated that approximately 11 hues could be absolutely identified, which is comparable to the estimate by Halsey and Chapanis of between 10 and 12 different hues.

The comparision of surface color and colored light research is commonly made for studies limited to hue alphabets. However, such comparisons should be made more cautiously when brightness and saturation are also varied. An example of this latter type of research with colored lights was reported by Bishop and Crook (1961). These researchers conducted a study to determine the number of colors that could be absolutely identified by subjects with normal color vision when viewed against various colored backgrounds. Stimulus luminance level ranged between 1, 10, and 100 fL; and purity levels were varied from 10% to the maximum (see Table 8) in this study.

Bishop and Crook found that subjects could learn to identify 28 different colored lights of maximum purity at the three luminance levels against a white background during a first phase of training. In latter phases of training subjects were able to identify the 28-color alphabet errorlessly when both stimulus and background purity was as low as 50%. Lesser levels of stimulus and background purity resulted in less than optimal identification. Subjects reported that stimulus colors looked different on colored backgrounds, but the reported findings indicate that after additional practice, identification is no more difficult after additional practice with colored backgrounds than with white backgrounds. Identification performance decreased when the visual angle subtended by stimuli was reduced from 20 minutes to 10 minutes. The researchers concluded that between 50 and 70

TABLE 8

COLORS AND PURITY LEVELS USED BY BISHOP AND CROOK (1960)

Color	Catalog Designation	Dominant Wave Length	Excitation Purity (%)
Red	Corning 2-78	630	100
Orange	Wratten 72B	606	100
Yellow	Corning 3-110	588	100
G-Yellow	Wratten 73	574	100
Y-Green 1	Corning 4-102	552	100
Y-Green 2	Wratten 74	538	96
Green	Corning 4-105	521	82
B-Green	Corning 4-104	500	92
G-Blue	Wratten 75	492	88
Blue	Corning 5-60	461	97

colors could be identified accurately in a laboratory setting with extensive training when hue, luminance, and purity are varied; however, this estimate was not validated.

In summary, the research selected for review indicates that selection of items for hue alphabets should be based on equal discriminability functions that have been established through research (i.e., Judd, 1932; Wright, 1947; Wulfneck et al., 1958). The research also indicates that the size of optimally identifiable hue alphabets is between 8 and 12. However, the studies reviewed have varied in the specific hue alphabets adopted. Additionally, the size of a color alphabet varying in hue, luminance, and purity is apparently much larger than an alphabet varying solely in hue; however, more research in this area is required. Finally, the influences of viewing conditions, display conditions, and individual differences on color identification suggest that research findings should not be extended beyond the conditions simulated in specific experiments. In their review of this area, Semple et al. (1972) concluded that "Due to the extreme interaction between the human visual process and the parameters associated with light and color, it would be impossible to predict performance with any degree of certainty without direct empirical validation with the systems to be employed." It appears then, that previous research can provide a foundation for the specification of hue and color alphabets, but empirical research with specific display systems, environmental conditions, and user populations is required if a usable code is to be established. An example of this type of work is Taylor and Belyavin's (1980) recent work in establishing color alphabets for moving maps projected by filmstrips.

SECTION 9
FLASH RATE CODING

DEFINITION

Flash rate coding involves the temporal fluctuation, or blinking, of a light source at a specific frequency. The frequency of fluctuation, then, is the primary stimulus attribute that is manipulated in this dimension of coding. Since flash-rate coding is limited to the fluctuation of a light source, it is unnecessary to consider its adaptation to point, line, and area symbols. In each case, the use of flash rate coding would involve the flashing or blinking of a specific portion of the display.

One adaptation of flash rate coding is a method termed flicker coding. Flash rate coding and flicker coding differ with respect to the perceived constancy of symbol display. Flash rate coding involves alternating on/off display of a symbol; whereas flicker coding involves alternating bright/dim display.

IMPORTANT ISSUES IN FLASH RATE CODING

Flash rates have traditionally been viewed as having limited application in visual coding because flashing symbols are both annoying and distracting. The utility of flash rate coding can best be characterized by the number of different flash rates that can be identified by observers and its special value as a coding dimension. The possible detrimental aspects of this coding dimension can be assessed by comparing observer performance with symbols that are not flash rate-coded in the presence and absence of flashing symbols.

GENERAL CONCLUSIONS

Although relatively little research applicable to flash rate coding has been conducted, the following general conclusions can be derived from previous work.

- The recommended range of flash rates is between .5 and 30 cycles per second.
- Five different flash rates can be accurately identified under optimal conditions with extensive practice. The probable maximum number of flash rates that can be used in an operational setting is between two and four.
- The onset of a flashing light is more useful for interrupting an ongoing task than the onset of a steady light.

- Flashing symbols have been shown to be useful in aiding search for target symbols on an electronic display.
- Prolonged symbol flashing has not been shown to degrade search performance. However, it has been shown to decrease legibility in a prolonged reading task.

APPLICABLE RESEARCH

The range of flash rates that can be used is limited at the higher frequencies by the flicker fusion rate—the frequency at which an intermittent light source is perceived as steady. The frequency at which flicker fusion occurs is dependent upon several factors, including brightness contrast, on/off ratio, and signal intensity. Flicker fusion has been studied much more intensively than the possible utility of flashing lights in visual displays. A commonly accepted range of frequencies for flash rate coding is that recommended by Gebhard (1948), which is between .5 and 30 cycles per second. The upper range was established so that this dimension of coding would be well below the flicker fusion rate, under most signal conditions.

Most of the research in flash rate coding has been concerned with its utility in presenting a single signal, usually for the purpose of signaling emergency conditions. In such cases, the alphabet size is usually two (steady and blink). Gerathewohl (1953) experimentally confirmed the utility of flashing lights as a conspicuous signal. He compared the time required for an ongoing task to be interrupted by the onset of either a steady or flashing light at low levels of brightness contrast. The flashing light was found to be superior for this purpose. In subsequent research, Gerathewohl (1954) determined that variations in frequency, rather than duration, of flash, was the most important characteristic for quickly interrupting a complex motor task. He also found that interruption of such a task was faster for higher flash frequencies, although three flashes per second was the highest frequency used in his study.

Cohen and Dinnerstein (1958) conducted a study to determine the practical size of a flash code alphabet. Ten subjects attempted to identify different sets of blink codes selected from nine frequencies ranging from .25 flash per second to 12 flashes per second. Subjects could identify a maximum of five flash rates under optimal conditions. However, identification errors still occurred when four flash rates were used. The authors recommended the use of only three flash rates in operational conditions, 4 per second, 1 per second, and .33 per second.

Goldstein and Lamb (1967) conducted a brief psychophysical study to determine four easily discriminable flash rates under 20 flashes per second. On-off ratios and flash rates were varied until four easily discriminable flash rates were obtained. They found that equal on-off ratios were as effective as unequal ratios. The four maximally discriminable codes they selected were: .05 second on and .05 second off, .20 second on and .20 second off, .50 second on and .50 second off, 1.20 second on and 1.20 second off.

Crawford (1962, 1963) conducted a series of studies concerned with the problem of automobile drivers detecting traffic signal lights in a background of irrelevant lights. In his research, single target lights appeared sequentially over a large visual display extending 44 degrees vertically and 92 degrees horizontally. Observers were required to detect each target light in a background of non-target lights of other colors. Crawford varied both the number of non-target lights and the flashing of both target and non-target lights.

In his first study, Crawford (1962) found that the fastest response was to the onset of a flashing target against a steady background. The slowest response was to a flashing target against a flashing background. Overall, a flashing background was found to result in an increase in response times. Crawford (1963) then varied the number of background lights that flashed. In this study he found that the advantage in response time gained by the use of a flashing signal was lost with the addition of even one flashing background light. This last finding could be interpreted as suggesting that the onset of a flashing symbol interferes with the detection of other coded information on a display. However, the nature of Crawford's simple detection task, the size of the display used, and the use of colored lights, rather than symbols, limit his findings to the driving environment for which the research was designed.

Smith and Goodwin (1971) conducted a study to evaluate the utility of using flash rate coding as a redundant information code. Three aspects of this evaluation were: (1) the effect on detection of flashing a class of items, rather than a single symbol; (2) the effect of symbol flashing on legibility; and (3) interference or distraction in task performance resulting from irrelevant flashing symbols.

The subjects searched for target items on a CRT display (see Figure 34). the results of the first experimental session are depicted in Figure 35. Use of flash coding was found to reduce search time by approximately 50% over the three display densities. Display density resulted in longer reaction time; and the saving in search time produced by flash coding increased for displays of greater density.

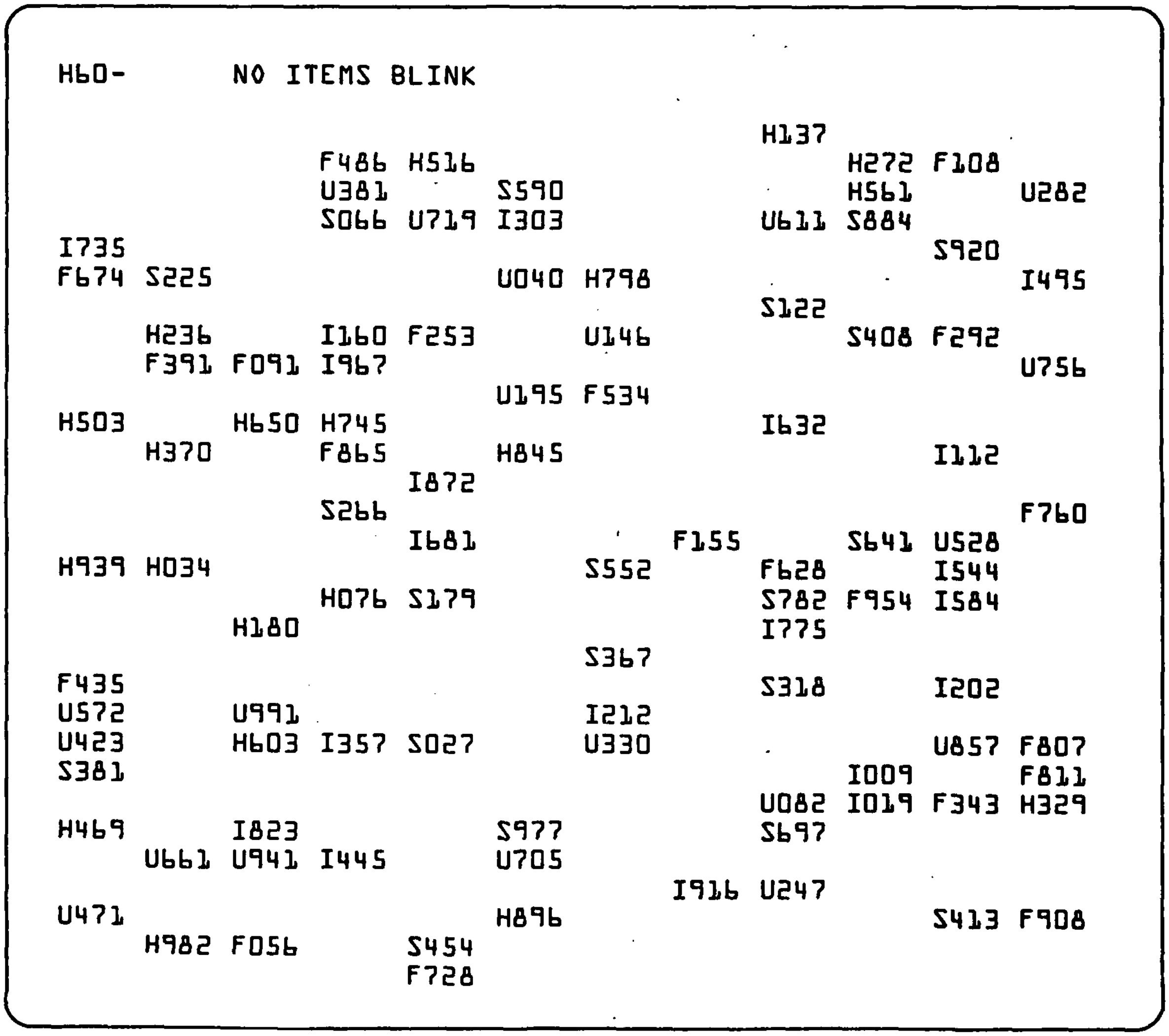


Figure 34. Example of the arrangement of symbols in the display used by Smith and Goodwin (1971).

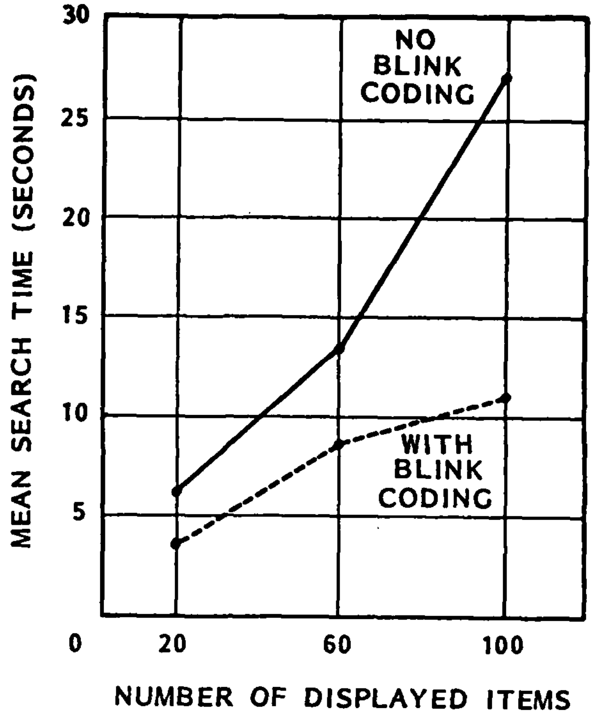


Figure 35. The relationship between search time, display density, and type of coding. (Adapted from Smith and Goodwin, 1971.)

During a second experimental session, subjects performed the search task under five additional display conditions, all at a density of 100 items. The five new conditions were: (1) all items not beginning with the designated target letter flashing; (2) only the designated letter, rather than all four characters, flashing; (3) all 100 display items flashing; (4) 50 items, not including the target item, flashing; and (5) 50 items, including target items, flashing. The search times for this second session were analyzed with the data from the flash and no flash conditions of the first session in which display densities of 100 items were presented.

The average search times for each of the seven 100-item display density conditions are presented in Table 9. Analysis of the differences in search time between these conditions indicated that any type of flash coding that was relevant to the designated target (first letter of target item, entire target item, and non-target item) facilitated search compared to conditions of irrelevant flash coding. There were no significant differences between the three blink conditions where flash coding was relevant. Additionally, there was no significant difference between the conditions in which all items flashed and no items flashed, suggesting that flash coding does not decrease legibility of alphanumerics, as evaluated in a random search task of this type.

TABLE 9

MEAN SEARCH TIMES FOR 100-ITEM DENSITIES
(from Smith & Goodwin, 1971)

Code Condition	Mean Search Time (seconds)
Target Letter Blink	10.6
Item Blink	10.9
Nontarget Blink	14.0
All Blink	23.4
50% Nontarget Blink	26.4
No Blink	26.8
50% Target and Nontarget Blink	33.0

Smith and Goodwin (1971) were concerned that their evaluation of legibility was not sufficiently sensitive to allow the conclusion that flash coding does not *decrease legibility. In a subsequent study* (Smith and Goodwin, 1972) they confirmed their doubts by demonstrating a 10% decrease in prolonged reading rate when an entire display of prose was flashed at a 3 cycle per second (.17 second on, .17 second off) rate.

The results of the reviewed research suggest several conclusions. First, the size of a useful flash code alphabet is limited to between two and four rates. Second, the presence of a flashing symbol is readily identified and use of this dimension to aid search is valuable. Third, the presence of irrelevant flashing signals negates the value of flash coding in aiding search. Finally, prolonged flashing of an entire display decreases symbol legibility in prolonged reading tasks.

SECTION 10
STEREO DEPTH CODING

DEFINITION

When stereo depth coding is discussed in the context of electronic displays, the factor of binocular disparity is of primary concern. As a factor of display, binocular disparity can be defined via an angular measure; namely, the difference between two angles of convergence, each originating from two points 65 mm apart (the average distance between two eyes) and each intersecting at separate points in space. Figure 36 depicts a scale drawing of two angles of convergence for points 100 mm and 300 mm from the eyes. For this example, the angular measure of binocular disparity equals $36^{\circ} - 12^{\circ} = 24^{\circ}$. Binocular disparity can be achieved with electronic displays by either simultaneous or alternating presentation of disparate perspectives of the same field of view on a display. These display techniques require the use of goggles by the observer so that different perspectives may be presented to each eye, usually by lenses of different color or polarity that are matched with the two display perspectives.

As a dimension of display perception, stereo depth coding refers to the perceived difference in depth of two points, or two areas of a single object, in the visual field. There is little need to consider the alternative methods available for coding point, line and area symbols with this dimension. In all cases, such coding would be based upon the specification of the forms or areas to be coded and the angular disparity displayed.

IMPORTANT ISSUES IN STEREO DEPTH CODING

Stereo depth coding on electronic displays represents a relatively new and exotic dimension of visual coding. The basic issues of importance in considering the use of this dimension are the degree of observer accuracy to be expected and its feasiblility in specific operational settings.

GENERAL CONCLUSIONS

The following general conclusions about the use, value, and feasibilty of stereo depth coding can be drawn from the literature reviewed.

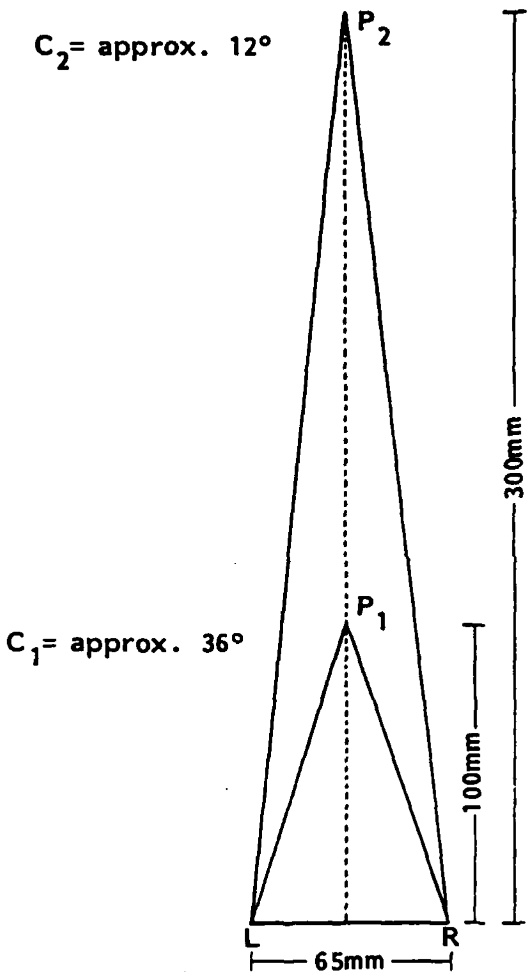


Figure 36. Scale drawing of two angles of convergence for points 100 mm and 300 mm from the eyes.

- When using binocular disparity to code actual distances that an observer is expected to identify absolutely, a limit of four different distances has been recommended.
- When using binocular disparity to code distant features beyond 20 feet, such as topographic relief, only relative distances can be coded.
- Feasibility studies are recommended prior to any attempt to implement this coding dimension.

APPLICABLE RESEARCH

Cohen (1955) investigated the use of binocular disparity as a technique for coding information. He found large individual differences in the range of binocularly disparate images that subjects could "fuse," or perceive in depth. This finding suggests that the range and number of levels of a depth code that could be absolutely identified would also be highly variable between individual observers. Cohen's data suggest that a depth code alphabet based solely on binocular disparity should be limited to four steps.

Binocular disparity has been used to code the relative distances of topographic features via aerial photography for many years. The results from a study conducted by Jenks and Caspall (1967) suggest the use of a ratio of vertical exaggeration so that stereo depth coding of topographic features appear "realistic" to experienced map readers. The exaggeration ratio is given in the following equation:

$$\text{Vertical Exaggeration} = 6.87 - 2.82 \log \text{contour interval (feet)}$$

This is recommended for large-scale topographic maps (1:24,000 and 1:31,680). These authors did not conduct research for small scale maps.

Stereo depth coding on electronic displays can be implemented via a number of techniques. (See Leibowitz & Sulzer, 1965; Roese & Khalafalla, 1975; Twell, Ray, Meirick & Polhemus for a discussion of some alternative techniques.) Pepper, Cole, Merritt, and Smith (1978) report a comparison of two of these techniques, the Fresnel and Field Sequential. A discussion of these techniques or comparisions between alternative techniques is, however, beyond the scope of the present report.

Neither the present level of technical implementation nor the research in observer use of depth coding in electronic displays is sufficient to lead to a recommendation concerning its use. Prior to any attempt to actually implement this coding dimension, extensive research in technical implementation and observer performance would be necessary.

SECTION 11
APPARENT MOVEMENT CODING

DEFINITION

The processing and presentation capabilities of visual display terminals that allow the use of flash rate coding also allow the use of a more complex dimension--apparent movement. The term "apparent movement" has been used traditionally to refer to the phenomenon of perceived motion when the stimulus is not moving physically. As noted by Kaufman (1974), the terms "apparent" and "real" are misleading, since perception of movement in both cases is the result of the stimulation of separate receptors on the retinal surface of the eye. However, the terms serve the purpose of distinguishing between intermittent and continual presentation of a stimulus. In the case of electronic displays, only the conditions leading to apparent movement can be displayed. Following is a brief summary of the possibilities for coding via apparent movement.

Apparent Movement-coded Point Symbols

The position of a discrete symbol can be moved with respect to either a stationary background or with respect to other features within a moving background. Additionally, components of a symbol can be displaced in more complex manners, which can be classified as methods of animation.

Apparent Movement-coded Line Symbols

Two basic methods employing apparent movement coding with line symbols are to either displace an entire line with reference to a stationary background or displace components comprising a line. The first type of coding can be used to transmit information concerning a change in the location of a demarcation; whereas the second can be used to increase the conspicuity of a demarcation.

Apparent Movement-coded Area Symbols

The methods of coding area symbols using apparent movement are analogous to those that can be employed with line symbols. Either the entire area can be displayed or sets of symbols within an area can be displaced in unison.

IMPORTANT ISSUES IN APPARENT MOVEMENT CODING

The present discussion of apparent movement coding is concerned with three issues related to this type of coding. The first issue considered is that of the basic conditions necessary for the perception of apparent movement. The second issue concerns the possible value of producing these conditions, rather than those leading to the perception of simultaneous presentation or successive position. Finally, the type of information that can be coded via apparent movement coding is considered.

GENERAL CONCLUSIONS

The following two general conclusions about the conditions influencing the perception of movement have been drawn from the research reviewed.

- The three most important factors which influence apparent movement perception are: (1) the time interval between successive symbol exposures, (2) the distance between displayed symbols, and (3) the intensity of symbol illumination.

- With a constant symbol illumination, as the distance between displayed symbols is increased, it is necessary to increase the delay between successive presentations for movement, rather than simultaneity, to be perceived.

- Although the perception of simultaneous symbol presentation would preclude conveying information related to symbol movement, the perception of successive position may not reduce the amount of information transmitted.

- It may be useful to distinguish between information conveyed by apparent movement when: (1) a display target is depicted, or (2) information not related to actual object position is depicted. Research concerning this issue is lacking. The determination of the optimal use of apparent movement coding in a symbology system would require additional research.

APPLICABLE RESEARCH

The data processing capabilities of modern display terminals has markedly increased the potential for using simple symbol movement or more complex animation for information coding. However, little applied research concerned with establishing such code alphabets has been conducted, with the exception of research in target tracking symbology. An initial issue in establishing an apparent movement alphabet concerns the conditions under which movement is perceived. Basic research in this area is briefly reviewed below.

Electronic displays can present two nominally identical symbols in two positions by either presenting the two symbols simultaneously or successively. The stimulus conditions that result in the perception of motion can be defined phenomenally as intermediate between the perception of simultaneity and the perception of succession. A symbol presented sucessively in two display locations can still be perceived as two symbols presented simultaneously if the stimulus conditions necessary for apparent movement perception are not met. Early research by Korte (1915) demonstrated that three important factors which influence the perception of apparent movement are the time interval between successive symbol exposures, the distance between the two symbol positions, and the intensity of illumination. These are also impotant factors in modern displays.

Corbin (1942) studied the relationship between symbol position and delay between successive exposures. Corbin varied the distance between two light stimuli from 2 inches to 12 inches and increased the exposure delay until each of four subjects indicated that the light appeared to move, rather than to be presented simultaneously in two positions. Average "simultaneity-motion thresholds" for the four subjects are shown in Table 10. The basic finding of this research was that as the distance between the two positions increased, it was necessary to increase the delay between successive presentations for apparent movement, rather than simultaneity, to be perceived.

Orlansky (1940) studied the effect of symbol similarity on the perception of apparent movement. In this study, symbol orientation, rather than shape, was used to define similarity. Orlansky found that when symbol distance and delay between

TABLE 10

SIMULTANEITY-MOTION THRESHOLD (from Corbin, 1942)

Separation (inches)	2	4	6	8	10	12
Threshold (second)	0.104	0.114	0.129	0.146	0.157	0.173

successive exposures were adequate for observers to perceive movement with identically oriented arrows, greater divergence in orientation resulted in fewer observers reporting motion. In such cases, it was necessary to increase the delay between presentations of dissimilar symbols for the perception of movement and rotation to be reported.

In addition to stimulus factors that influence the perception of apparent movement, observer factors have also been identified. De Silva (1926) and Neuhaus (1930) have reported that practice facilitates the perception of movement. These researchers note that many subjects report no motion in laboratory settings on the first few trials, and some subjects require extensive practice. Stratton (1911) also identified the factor of perceptual set. He reports that observers who maintained a critical, analytic attitude were less likely to report the perception of movement. There is a possible flaw in such inferences, however, since an observer's attitude and practice could also be related to their willingness to report movement. That is, observer bias to report a given perception is confounded with such factors as learning and perceptual set.

The types of information that are most closely associated with symbol movement are direction, speed, and acceleration. If these characteristics are to be used to convey information other than target location, it is important to consider the number of identifiable steps for each of these separate attributes. (Note that a direction-of-movement alphabet would likely be comparable to a lineal inclination alphabet.) However, if symbol movement is used to convey target location, actual direction, speed, and acceleration should be used in coding these dimensions of movement.

SECTION 12

EVALUATION OF CODING DIMENSIONS FOR TOPOGRAPHIC & TACTICAL DATA DISPLAY

This section presents an evaluation of the relative utility of each of the ten coding dimensions for coding and display of topographical and tactical data. The relative utility of each coding dimension is assessed on the basis of three general evaluation criteria. These criteria are: (1) the number of different steps within each dimension that can be used for coding topographic and tactical data, (2) the compatibility of each dimension with different scaling categories used to convey information, and (3) the relative value of each dimension in aiding the aviator in searching for a specified symbol in a display. Each of the following three subsections compares the coding dimensions discussed in the preceding sections with respect to one of these criteria. A final subsection summarizes the conclusions reached with respect to each criterion.

CODING STEPS

Definition

A coding step is a specific value or instance from a coding dimension. The amount of information that can be conveyed by one dimension is a function of the number of absolutely identifiable steps within that dimension. Thus, estimates of the number of absolutely identifiable coding steps can then be used to compare the relative amounts of information that can be conveyed by each of the ten coding dimensions.

Determining the Maximum Number of Coding Steps

Coding dimensions can be categorized on the basis of their complexity. In general, less complex dimensions have fewer absolute identifiable coding steps than more complex dimensions. A number of the coding dimensions discussed in this report represent a single stimulus attribute. Following S.S. Stevens' (1934) suggestion, a stimulus attribute can be defined procedurally as a perceived characteristic of a stimulus that can be judged as remaining constant while other characteristics of the stimulus vary. For example, each of the three basic attributes of light--hue, brightness, and saturation--can be judged to remain constant while the other attributes of a light source are varied. No more than three such attributes can be identified by observers when viewing a light source. Therefore, brightness can be said to be a simple coding dimension and color a complex dimension.

The number of attributes that comprise a coding dimension is related to the number of absolutely identifiable coding steps within the dimension. G.A. Miller (1956) is noted for pointing out that the number of absolutely identifiable coding steps for dimensions based on one stimulus attribute is limited to approximately seven. Miller hypothesized that this limit in the absolute identification of stimuli varying on the basis of one stimulus attribute is the result of a fundamental limitation in the human capacity to process discrete bits of information. He termed this processing limitation the **span of absolute judgment.**

Our ability to make an absolute judgment about a single stimulus attribute is said to be limited by our span of absolute judgment. Our ability to remember a set of judgments about different stimulus attributes is limited by our **span of immediate memory.** The human information processing span of immediate memory, like the span of absolute judgment, is commonly estimated to be limited to approximately seven items, or "chunks," of information. However, it is important that these two limitations in processing not be confused. Miller (1956) argues that the two processes related to these limitations must function independently to some degree, since we are able to identify more than seven different symbols composed of multiple stimulus attributes. Thus, a maximum of approximately seven symbols varying on the basis of the stimulus attribute of hue can be absolutely defined; but if brightness and saturation are also varied, the number of absolutely identifiable coding steps for the resulting dimension of color increases markedly. It is equally important to recognize that the processes of absolute judgment and immediate memory are interrelated. That is, concurrent processing of one type apparently reduces the processing span for the other type. .Thus, when hue, brightness, and saturation are combined, identification accuracy of any one attribute is reduced in comparision to the case when that attribute is presented alone.

Simple coding dimensions. Dimensions that are based upon a single stimulus attribute are referred to as simple coding dimensions in this report. Six stimulus attributes which represent one of the ten coding dimensions, or attributes of one of these dimensions, are:

- Width
- Height
- Length
- Density
- Brightness
- Flash rate

Research applicable to specifying the maximum number of absolutely identifiable coding steps for several of these dimensions was reviewed in Section 2. The results of this research are generally consistent with Miller's (1956) statement that a limit of approximately seven coding steps can be accurately identified within each of these simple coding dimensions under optimal conditions. However, the experimental results show some variation in this number between and within dimensions. Under various conditions in the operational setting, the maximum number of steps is reduced. This reduction is the result of such factors as changing ambient illumination and introducing concurrent tasks. Under operational conditions, the recommended maximum number of coding steps for these simple coding dimensions is between two and five.

Complex coding dimensions. Dimensions which are based upon multiple stimulus attributes are referred to as complex coding dimension in this report. Eight complex coding dimensions which represent one of the ten coding dimensions, or specific applications of a coding dimension are:

- Shape
- Alphanumerics
- Area
- Absolute number
- Inclination
- Color
- Stereo depth
- Apparent movement

In general, the maximum number of absolutely identifiable coding steps under optimal conditions for these dimensions is related to the number of component stimulus attributes. Limitations in this maximum number are related to restrictions in our ability to make accurate judgments while holding prior judgments in short-term memory or while performing other tasks concurrently, and to restrictions in operational conditions which limit sensory abilities.

It is often necessary to estimate the number of absolutely identifiable coding steps of complex coding dimensions. Unfortunately, research data is often unavailable or inapplicable. Previous research permits reasonable estimates of the number of coding steps for geometric shapes, pictorial symbols, alphanumerics, inclination and color. However, applicable research with stereo depth and apparent movement is lacking. When empirical data are lacking, an analysis of the number of attributes comprising a complex dimension and comparision with dimensions with a similar number of attributes can be used as an aid in making estimates.

Summary of Maximum Number of Coding Steps

General estimates of the maximum number of coding steps in optimal conditions and typical operational conditions are provided in Table 11. The coding dimensions are grouped into simple and complex sets. The estimates for simple dimensions are based on extensive research and are reasonably accurate. It is fundamentally more difficult to determine the maximum number of coding steps for complex coding dimensions. The estimates provided are more variable than those for simple dimensions, and validation with an operational system is especially necessary with these more complex coding dimensions. In some cases, there is not sufficient experimental data to support any estimate.

SCALING CATEGORIES

Definition

Coding dimensions differ in the precision of quantitative information that they can convey. The different levels of precision in quantitative information are known as **scaling categories.** There are three scaling categories of interest in coding topographical and tactical data. **Nominal** scaling consists of classification by qualitative attributes (such as male vs. female). **Ordinal** scaling involves ranking (such as small vs. large). **Interval** scaling requires measurement rather than simply

TABLE 11

MAXIMUM NUMBER OF CODING STEPS FOR CODING DIMENSIONS UNDER OPTIMAL AND OPERATIONAL CONDITIONS

SIMPLE CODING DIMENSIONS	OPTIMAL	OPERATIONAL
SIZE		
Width	4-6	2-4
Height	4-6	2-4
Length	4-6	2-4
NUMEROSITY		
Density	5-7	3-5
BRIGHTNESS	5-7	3-5
COMPLEX CODING DIMENSIONS		
SHAPE		
Geometric	20-40	10-30
Pictorial	Unlimited	?
ALPHANUMERIC	Unlimited	Unlimited
SIZE		
Area	5-7	3-5
NUMEROSITY		
Absolute	5-7	3-5
INCLINATION	16-24	12-16
COLOR	50-70	10-30
STEREO DEPTH	?	?
APPARENT MOVEMENT	?	?

ranking (such as distance in meters). Different coding dimensions vary in their compatibility with different scaling categories. However, if a dimension is compatible with interval scaling, it is compatible with the other two categories of scaling. Similarly, a coding dimension that is compatible with ordinal scaling is also compatible with nominal scaling.

Nominal Scaling

All coding dimensions are compatible with nominal scaling. That is, any dimension can be used to refer to qualitative attributes of referents in a coding system. This fact is somewhat counter-intuitive, since we commonly think of dimensions based upon orders of magnitude as incompatible with qualitative attributes. A common example of a nominal scale using what is usually considered a dimension varying in magnitude is the jersey number of a football player. In this case, numeric coding is used to refer to a player's identity.

Ordinal Scaling

Coding dimensions that are judged on the basis of single stimulus attributes that can be easily rank-ordered (size, density, brightness, and flash rate) are compatible with ordinal scales. However, these dimensions are not compatible with interval scales, since estimates of magnitude based upon these dimensions tend to involve systematic error. For example, estimates of the actual length of objects has been shown to be best described by a logarithmic function, which tends to result in inaccurate estimates of the interval measure of length (inches, feet, meters, etc). Inclination coding, stereo depth coding, and apparent movement coding are also compatible with ordinal scaling. However, systematic errors in estimation for these dimensions, similar to the errors observed for single stimulus attributes, make inclination, stereo depth, and apparent movement incompatible with interval scaling.

Coding dimensions that are not highly compatible with ordinal scaling are those which do not readily lend themselves to judgments based on a simple sensory attribute. Geometric, pictorial, and color coding fall into this classification. These dimensions can be used for purposes of ordinal scaling by specifying a component attribute (e.g., curvature, width, or saturation). However, the rank ordering of these attributes tends to be less accurate than for attributes of relatively simple coding dimensions.

Alphanumeric coding and absolute number coding are compatible with ordinal scaling. In the case of letters, this is the result of the common ordering of these symbols from A to Z. In the case of numerals, this is the result of consistently associating the shape of the symbols with numbers of items. Finally, the counting inherent in absolute number-coding leads to the compatibility of this type of coding with ordinal scaling.

Interval Scaling

Interval scaling can only be used with codes in which actual counting occurs or learned associations with counting exist, since systematic errors in estimating the value of other attributes of symbols, such as size, result in corresponding errors in the interval values associated with those attributes. Thus, only absolute number coding and numeric coding are compatible with this scaling category. Absolute number coding, however, represents a crude method of interval scaling in comparison to numeric symbols.

Summary of Dimension-scaling Compatibility

The compatibility of coding dimensions with the three categories of scaling can be summarized on the basis of whether each dimension is (1) compatible; (2) compatible, but not recommended; or (3) incompatible with each scaling category. This classification is summarized in Table 12.

DISPLAY SEARCH

Definition

During the process of navigation, an aviator must frequently refer to topographic and tactical displays to ascertain some fact about the flight environment. If only the required information is being displayed, the aviator can view the display and proceed directly to the task of interpreting the coded information. Such a scenario is extremely unlikely, however, since topographic and tactical displays must present a complex array of symbolically coded data related to multiple aspects of the flight environment. Thus, it is more likely that the aviator must search among the symbols being displayed to locate the required coded information. Different coding dimensions vary in their relative value in aiding search. Assistance in search can be assessed operationally by measuring the time required to locate or identify a specified symbol coded with one of the 10 dimensions identified in this report.

Research Applicable to Display Search

The value of a coding dimension in aiding display search can be assessed in the context of several types of coding systems. In the present discussion, different

TABLE 12

COMPATIBILITY OF CODING DIMENSIONS WITH SCALING CATEGORIES

DIMENSION	SCALE Nominal	Ordinal	Interval
SHAPE			
Geometric	+	o	-
Pictorial	+	o	-
ALPHANUMERIC			
Letter	+	+	-
Numeral	+	+	+
SIZE			
Area	+	+	-
Width	+	+	-
Height/Length	+	+	-
NUMEROSITY			
Absolute	+	+	o
Density	+	+	-
INCLINATION	+	+	-
BRIGHTNESS	+	+	-
COLOR	+	o	-
FLASH RATE	+	+	-
STEREO DEPTH	+	+	-
APP. MOVEMENT	+	+	-

+: Recommended

o: Compatible but not recommended

-: Incompatible

types of coding systems can be distinguished on the basis of the dimensions used for coding and the way in which those dimensions are combined. The least complex assessment of the value of a dimension in aiding search involves the comparison of search times for separate unidimensional coding systems under comparable display conditions. Studies of this type have found that color-coded symbols are located relatively rapidly when compared to a number of different shape-coded symbols (Christner & Ray, 1961; Hitt, 1961; Smith & Thomas, 1964). Comparisons between different shape-coded alphabets indicate that symbols can be located rapidly in a cluttered display if they are either relatively easy to identify (Smith & Thomas, 1964) or the shapes are relatively simple geometric forms (Williams & Falzon, 1963a).

In addition to unidimensional coding systems, two other types of coding systems must be considered when evaluating the relative value of dimensions in aiding display search. These two systems are nonredundant (uncorrelated) and redundant (correlated) multidimensional coding systems. In nonredundant coding, the value of one dimension used to code a symbol varies independently from the value of other dimensions used in coding that symbol. For example, if the letters "A" and "X" and the colors red and blue were used to code symbols, a coding system would be nonredundant if each letter code is coded with both colors. In a redundant coding system, the value of one dimension is determined by the value of another dimension used to code a symbol. Using the example above, if "A" were always red and "X" were always blue, a redundant system for coding these letters and colors would be in use.

In multidimensional coding systems (where symbols may differ in two or more stimulus dimensions, such as color and shape), the experimental situation is more complex than unidimensional systems, and findings must be carefully analyzed. As pointed out by Christ (1975), the results of studies in symbol search have varied considerably between multidimensional systems depending upon whether the systems used redundant or nonredundant coding, and which of the codes the subjects were to search for.

Smith and Thomas (1964) compared search times for nonredundantly coded shape and color symbols. In this study, search times for specified colors were not affected by the specific shape-coded symbol on which colors were superimposed. However, search for shape-coded symbols was found to be somewhat faster when color did not vary between symbols. This finding suggests a trade-off in benefits when color coding is used in a nonredundant multidimensional coding system where subsets of items must be located on the basis of dimensions other than color and color is varied within these dimensions. Specifically, color coding can be used to aid search; but this approach will result in an increase in search time for shape-coded symbols if the observer must ignore color.

Williams (1967) compared search times using a set of nonredundantly coded symbols varying in color, size, and shape, with a unique two-digit numeral printed within each symbol. Subjects viewed a display with 100 symbols and were required to locate a target specified by a unique two-digit number. Search times were slowest when either the number alone or the number and shape of the target symbols were specified. Subjects were somewhat faster when the size (very large, large, medium, or small) was specified along with the number. Finally, search times were fastest when the number and color were specified. Additional specifications of more than two coding dimensions had a negligible effect on search time.

A number of studies have assessed the value of coding dimensions in aiding search with redundant multidimensional coding systems. Redundant systems can be either completely or partially redundant. In completely redundant systems, one symbol attribute is perfectly predictable from another, such as all dots (airfields) shown in purple, and purple used only for dots. In partially redundant coding systems, knowledge of one attribute is helpful, but not sufficient for identification of the other attribute. For example, blue is typically used to indicate water symbols, but does not identify the size and shape attributes pertaining to ponds, lakes, or streams.

In completely redundant coding systems, knowledge of the target color has been shown to facilitate speed of search by as much as 74% (Kanarick & Peterson, 1971). Even greater relative facilitation by color has been found when the density and complexity of the display is high. Dyer and Christman (1965) used a search task for alphanumeric characters with and without completely redundant color coding and found facilitation of as much as 300% when several hundred characters were displayed.

Color has also been shown to aid in the search of displayed symbols coded with a partially redundant system (e.g., Smith, 1963; Green, McGill, & Jenkins, 1953; Saenz & Richie, 1974). Partially redundant color codes facilitate search more when display density increases, but facilitate search less when the number of nontargets which have the same color increases (Green & Anderson, 1956). Cahill and Carter (1976) found that search times increased linearly with density, but found a curvilinear relationship with an increase in the number of colors used. In general, about four to nine colors seemed to produce the lowest search times in the study conducted by Cahill and Carter. However, an increase in the number of colors up to 28 has been shown to facilitate search time in a study conducted by Shontz, Trumm, and Williams (1971). In order for partially redundant colors to facilitate search, the subjects must be aware of the target color, otherwise the colors will prove detrimental to search, just as in the case of nonredundant codes (Green & Anderson, 1956; Smith, 1962).

A second dimension that has been shown to facilitate search with redundant coding systems is flash rate coding. Smith and Goodwin (1971) presented displays with several stimuli, each composed of one letter followed by three numerals. Target stimuli were designated by the first letter and numeral, and the observers' task was to report the final two numerals. The time required to complete this search task was reduced from the comparison condition, where no stimuli flashed, if the subset of symbols with the same first letter flashed on the display. In the case of highly cluttered displays, searching for a target when no symbols were blinking required more than twice as much time as when either the set of target or nontarget symbols were blinking. Flash rate coding has only been shown to facilitate search when only one flash rate has been used. In contrast, multiple colors have been shown to facilitate search.

No research related to the effect of numerosity, brightness, stereo depth, or apparent movement on search was found in the literature.

Summary of Experimental Findings in Display Search

A number of general conclusions can be derived from the research summarized above.

- Color has been shown to facilitate search in a wide variety of coding systems.
- When a single color is designated for search, an increase in the number of colors and a corresponding decrease in the number of symbols in each color results in more rapid search.

- The use of a single flash rate as a redundant dimension facilitates display search considerably.

- Knowledge of nonredundantly coded size facilitates search time moderately.

- Symbol shape has been shown to be one of the least valuable dimensions in aiding search. However, less complex geometric symbols are more rapidly located than pictorial or complex geometric symbols.

SUMMARY OF CODING DIMENSION EVALUATION

This section has compared coding dimensions on the basis of three general evaluation criteria that are relevant to the display and use of topographic and tactical information:

- The number of **coding steps** within each dimension.

- The compatibility of dimensions with three **scaling categories.**

- The value of dimensions in aiding **display search.**

Table 13 provides a summary of the evaluation criteria that should be used in guiding the designer of coding systems that are to convey topographic and tactical information. This table represents the relative virtues and disadvantages of each dimension in a generalized fashion.

Table 13 provides a final summary of the evaluation of each dimension. This summary could be used during preliminary symbology design to allocate dimensions to specific information and task requirements that are related to the three evaluation criteria.

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TABLE 13
SUMMARY OF CODING DIMENSION EVALUATION

DIMENSION	STEPS MAX	STEPS OP	SCALE NOM	SCALE ORD	SCALE INT	SEARCH
SHAPE						
Geometric	20-40	10-30	+	o	-	LOW
Pictorial	Unlimit	?	+	o	-	LOW
ALPHANUMERIC						
Letter	Unlimit	Unlimit	+	+	-	LOW
Numeral	Unlimit	Unlimit	+	+	+	LOW
SIZE						
Area	5-7	3-5	+	+	-	MOD
Width	4-6	2-4	+	+	-	MOD
Height/Length	4-6	2-4	+	+	-	MOD
NUMEROSITY						
Absolute	5-7	3-5	+	+	o	LOW
Density	5-7	3-5	+	+	-	LOW
INCLINATION	16-24	12-16	+	+	-	LOW
BRIGHTNESS	5-7	3-5	+	+	-	MOD
COLOR	50-70	10-30	+	o	-	HIGH
FLASH RATE	5-7	3-5	+	+	-	HIGH
STEREO DEPTH	?	?	+	+	-	?
APP. MOVEMENT	?	?	+	+	-	?

? : Insufficient research
+ : Recommended
o : Compatible but not recommended
- : Incompatible
LOW : Low value in aiding search
MOD : Moderate value in aiding search
HIGH : High value in aiding search

SECTION 13

EVALUATION OF COMBINED CODING DIMENSIONS FOR TOPOGRAPHIC & TACTICAL DATA DISPLAY

Discussion in the preceding sections has focused on unidimensional coding. However, practical considerations commonly demand the use of multidimensional coding in complex symbology systems. In this section, issues relevant to the evaluation of combined coding dimensions are discussed.

COMBINING CODING DIMENSIONS

The three basic ways in which coding dimensions can be combined to form multidimensional symbols are redundant, nonredundant, and partially redundant coding. In redundant coding, separate dimensions used to code the same information are combined in the design of a single symbol. For example, if a light beacon is always coded as a purple circle and the color purple can always be used to predict the presence of a circle, then a redundant combination of purple and circle has been used. In nonredundant coding, separate dimensions used to code different information are combined in the design of a single symbol. For example, if a light beacon is coded as a purple circle and a radio beacon is coded as a green circle, a nonredundant combination of color and shape is being used, since a specific color cannot be used to predict the presence of a circle. In partially redundant coding, one or more dimensions are used for nonredundant coding and additional dimensions are used to code the otherwise unique symbols into subsets. For example, all point features of a topographic map could be uniquely coded via shape coding, with subsets of these features (e.g., features of airfields, railroad features, highway features, etc.) coded into sets by the use of a different color for each subset.

Completely redundant, completely nonredundant, and partially redundant coding represent the primary ways in which dimensions can be combined in the design of multidimensional symbols. However, within a complex symbology system, hybrids of these three types of combination could be used. One possibility involves coding a subset of symbols via partially redundant coding, and coding the remaining symbols using completely redundant coding.

In determining the manner in which dimensions are to be combined in a symbology system, the designer must be responsive to two interrelated sets of design factors. The first set of factors involves the statistical possibilities that are available for coding information. Given a specified set of dimensions and coding steps within each dimension, the range of combined dimensions and number of different messages that can be coded with each type of combination is statistically predetermined.

The second set of design factors involves functional, rather than statistical, factors. Functional factors in symbology design include the information and task requirements related to a symbology system, as well as the operational setting. Functional factors must be considered by the designer so that the utility of the symbology system in the operational setting is maximized.

STATISTICAL DESIGN FACTORS

Two separate types of statistical factors must be considered by the symbology designer: the number of different multidimensional combinations available for coding and the number of different messages that can be coded by a symbology system.

Number of Different Combinations

The different combinations of dimensions that are available for the design of symbols is statistically limited. The number of unique combinations is determined solely by the number of dimensions that are compatible with one another for purposes of multidimensional coding. The present discussion assumes that all ten of the visual coding dimensions discussed in this report are compatible with one another.*

The ten dimensions identified in this report could be combined in sets of two, three, four, five, six, seven, eight, nine, and ten in coding an individual symbol. Although there is only one possible combination of ten dimensions, there

*In the next section, specific applications of dimensions will be shown to be incompatible with one another. However, there are examples from each dimension that are compatible with examples from all other dimensions.

are ten different combinations possible if a symbol were coded with nine dimensions. The **binomial coefficients** for each multidimensional set size can be calculated to determine the number of different combinations of dimensions that are possible in multidimensional coding (Hays, 1973). The calculations for set sizes of two to ten are presented in Table 14.

TABLE 14

NUMBER OF DIFFERENT COMBINATIONS OF THE TEN CODING DIMENSIONS INTO MULTIDIMENSIONAL SETS

MULTIDIMENSIONAL SET SIZE	POSSIBLE COMBINATIONS OF DIMENSIONS
2	$\frac{10!}{2!\,8!} = 45$
3	$\frac{10!}{3!\,7!} = 120$
4	$\frac{10!}{4!\,6!} = 210$
5	$\frac{10!}{5!\,5!} = 252$
6	$\frac{10!}{6!\,4!} = 210$
7	$\frac{10!}{7!\,3!} = 120$
8	$\frac{10!}{8!\,2!} = 45$
9	$\frac{10!}{9!\,1!} = 10$
10	$\frac{10!}{10!\,0!} = 1$
	TOTAL COMBINATIONS = 1,013

Across all multidimensional set sizes, the total number of different combinations can be determined by summing the values calculated for each set size. Thus, the total number of different combinations listed at the bottom of Table 14 (1,013) represents the total number of unique ways in which dimensions could be selected for multidimensional coding.

Number of Different Messages

The number of different messages that can be coded by a multidimensional symbology system can be calculated if three characteristics of the system are specified: (1) the number of coding dimensions, (2) the number of different coding levels within each dimension, and (3) the way (redundant, nonredundant, etc.) in which dimensions are combined. The number of different messages is maximized if completely nonredundant coding is used. However, completely nonredundant methods are not always advisable in symbology design, since some uses of redundant coding have been shown to facilitate search and identification of symbols (e.g., Brooks, 1965; Ericksen, 1952; 1953; Ericksen & Hake, 1955; Green & Anderson, 1956; Kanarick & Petersen, 1971; Markoff, 1972; Wong & Yacoumelos, 1972). Following are examples of the effects of different types of multidimensional combinations on the number of different messages that can be coded with a multidimensional coding system.

Completely nonredundant coding. The number of different messages that can be coded by a limited number of dimensions and levels within each dimension is maximized if completely nonredundant coding is used. Table 15 presents a simplified, hypothetical coding system in which two levels from each of the ten coding dimensions could be combined in a completely nonredundant manner. The number of different messages that can be coded in a completely redundant coding system equals the number of levels within each dimension raised to the power of the number of dimensions. When the number of levels are not equal for all dimensions, the number of messages equals the product for the sets of dimensions with an equal number of levels. For the example in Table 15, the number of different ten-dimensional messages (i.e., one force, armed with nuclear weapons, air support available, command, anti-aircraft capability, not currently under surveillance, friendly, not approaching, within range, not moving) equals 2^{10}, or

1,024. With fewer dimensions, the number of messages decreases exponentially. For example, with nine dimensions of two levels each, the number of messages equals 2^9, or 512; with eight dimensions the number of messages equal 2^8, or 256; etc.

TABLE 15

HYPOTHETICAL NONREDUNDANT TEN-DIMENSIONAL SYMBOLOGY SYSTEM FOR TACTICAL DATA DISPLAY

DIMENSION	VALUE	MEANING
Shape	Triangle	Armed with nuclear weapons
	Circle	Armed with conventional weapons
Alphanumerics	A	Air support available
	G	Ground force only
Size	Large	Command force
	Small	Not a command force
Numerosity	Single	One force
	Double	Two forces
Inclination	Pointer up	Anti-aircraft capability
	Pointer down	No anti-aircraft capability
Brightness	Dim	Not currently under surveillance
	Bright	Currently under surveillance
Color	Blue	Friendly force
	Red	Hostile force
Flash Rate	Steady	Not approaching
	Blink	Approaching
Depth	Close	Within range
	Far	Not within range
Movement	Stationary	Not moving
	Moving	In transit

A change in the number of levels within a dimension also affects the number of messages that can be coded with a completely nonredundant symbology system. The result of such a change can be easily calculated using the algorithm provided above. For example, if two additional colors were added to the symbology system in Table 15, the number of possible ten-dimensional messages would increase to $(2^9)(4^1)$, or 2,048. If two more shapes were also added, the number of possible messages would increase to $(2^8)(4^2)$, or 4,096. These exponential increases in the number of messages resulting from increases in the number of different messages only occur when nonredundant combinations of dimensions are used in a symbology system.

Completely redundant coding. The number of different messages that can be coded by a set number of dimensions and levels within each dimension is minimized if completely redundant coding is used. Referring to Table 15 again, a completely redundant coding system would use one step from each dimension to code the same message. For example, one step from each dimension could be used to code the presence of friendly forces and the remaining step from each dimension to indicate hostile forces; which would limit the total number of messages to two. This is an obviously impractical approach to multidimensional coding.

Partially redundant coding. This combination represents the intermediate possibilities between completely nonredundant and completely redundant combinations. An example of this approach, based on Table 15, could use blinking symbols to code those symbols referring to hostile forces with antiaircraft capability and steady symbols for all other symbols in an otherwise completely nonredundant symbology system. For this example, the dimension of flash rate is no longer coding unique information. This system would have the potential of coding 2^9, or 512 different messages.

Hybrids of different types of combinations. Hybrids of the three primary ways to combine dimensions can be used within a single symbology system. In general, when such an approach is taken, the number of dimensions and coding levels used for redundant coding exponentially reduces the number of messages in an otherwise nonredundant coding system. For example, the dimensions of size and shape in Table 15 could be used redundantly to code the type of weapon. If all other dimensions were used to code information nonredundantly, 2^9, or 512, different messages could be coded with this system. The reader should recall that 2^{10}, or 1,024, different messages could be coded in the completely nonredundant system.

A second type of combination hybrid involves independent sets of coded information. For example, the symbology system in Table 15 could be expanded to include four colors, eight shapes, and four inclinations. In a completely nonredundant system, the number of possible messages resulting from this set of dimensions and levels would be $(2^7)(4^2)(8^1)$, or 16,384. However, if two colors, four shapes, and the size dimension were used to code nontactical data nonredundantly and the remaining dimensions and levels were used to code only tactical data nonredundantly, the possible number of messages would be reduced from 16,384 to $(2^2)(4^1)$ + $(2^6)(4^1)$, or 262.

FUNCTIONAL DESIGN FACTORS

In Section 3, individual coding dimensions were evaluated on the basis of three criteria relevant to symbology design: (1) the number of coding steps, (2) the compatiblity of each dimension with scaling categories, and (3) the relative value of each dimension in aiding search. The latter two of these unidimensional criteria are also applicable to the case of multidimensional symbology design. However, it is necessary to reconsider the first of these criteria for the case of combining symbols. When considering the number of levels available for coding in each dimension in multidimensional systems, the **compatibility of dimensions** must first be considered. Additionally, the **number of multidimensional levels that can be identified** must be considered independently of the criteria established for unidimensional coding. These two additional criteria will be considered in the remainder of this subsection.

Compatibility of Dimensions

It is important to recognize that some applications of unidimensional coding are incompatible with one another when an attempt is made to combine them into a single multidimensional symbol. Egeth and Pachella (1969) have used the term "interdimensional interference" in discussing combinations in which certain levels within one dimension make the identification of the level of a second dimension more difficult. An analytic evaluation of the possible bidimensional coding pairs can lead to the tentative specification of incompatible coding dimensions. Figure 37 depicts the results of such an evaluation conducted by the present authors. Nine bidimensional combinations were identified as likely to result in interdimensional interference. Two general explanations are suggested for such interference.

- A reduction in the ability to identify specific shape characteristics required for symbol identification. This would be likely to occur if alphanumeric symbols were combined with orientation or lineal inclination coding, and if geometric symbols were to be combined with height, width, length, orientation, or pictoral coding.
- A fundamental physical or psychophysical interrelationship between coding dimensions. This type of interrelationship exists between area and other methods of size coding, orientation and lineal inclination, absolute number and density coding, and brightness and color coding.

The pairs of incompatible dimensions mentioned above do not exhaust such possibilities. With extreme levels of certain dimensions, such as very rapid movement and very dim symbols, interdimensional interference would also be observed. When more than two dimensions are to be combined, incompatible pairs should not be included. However, compatibility of such higher order combinations is not assured simply because all pairs from the proposed combination are compatible in bidimensional combinations.

Identifiable Levels of Multidimensional Symbols

The combination of compatible dimensions with levels that are easily identified in unidimensional symbols does not ensure that identification accuracy will remain equally high in the resulting multidimensional symbols. Additionally, the resulting level of identification accuracy is affected by the way in which dimensions are combined. The effect of each of the three major ways to combine dimensions on symbol identification is considered below.

Completely redundant combinations. This combination of compatible dimensions does not reduce the number of coding levels within each dimension. Indeed, when compatible dimensions are combined to code the same message, symbol identification has been found to be better than in the unidimensional case (Ericksen & Hake, 1955). Ericksen and Hake have interpreted their findings in

	ALPHANUMERIC	GEOMETRIC	PICTORIAL	H,W,L	AREA	ABSOLUTE	DENSITY	ORIENTATION	LINEAL	BRIGHTNESS	COLOR	FLASH RATE	STEREO DEPTH
SHAPE-GEOMETRIC	●												
SHAPE-PICTORIAL	●												
SIZE-HEIGHT, WIDTH, LENGTH	●		●										
SIZE-AREA	●	●	●										
NUMEROSITY-ABSOLUTE	●	●	●	●	●								
NUMEROSITY-DENSITY	●	●	●	●	●								
INCLINATION-ORIENTATION			●	●	●	●	●						
INCLINATION-LINEAL		●	●	●	●	●	●						
BRIGHTNESS	●	●	●	●	●	●	●	●	●				
COLOR	●	●	●	●	●	●	●	●	●				
FLASH RATE	●	●	●	●	●	●	●	●	●	●	●		
STEREO DEPTH	●	●	●	●	●	●	●	●	●	●	●	●	
APP. MOVEMENT	●	●	●	●	●	●	●	●	●	●	●	●	●

Figure 37. Summary of an analytical evaluation of bidimensional compatibility (● signifies compatibility).

identification accuracy as resulting from an increase in the amount of information transmitted by compatible dimensions combined with complete redundancy. If this interpretation is correct, it follows that the number of coding steps within each dimension could be increased in certain cases of redundant coding.

With the exception of incompatible dimensions, increased identification accuracy is expected to result from completely redundant coding. However, this type of coding must be used prudently by designers of symbology systems; since it dedicates available dimensions to coding a more limited number of messages. As described in Section 3, this type of coding can also be used to reduce search time.

Therefore, in cases where very important messages require the optimization of location and identification performance, redundant coding should be considered.

Partially redundant coding. One explanation that has been proposed for the improvement in identification accuracy with redundant coding involves the reduction in observer uncertainty. Thus, completely redundant codes allow the observer to compare completely correlated sources of information. In contrast, partially redundant codes allow observers to use the partially redundant dimension to delimit the set of possible messages coded by a symbol. The facilitation of identification accuracy by partially redundant color codes has been reported by Wong and Yacoumelos (1973) using a TV display, and by Markoff (1972) using static g d photographs.

The choice between completely redundant and partially redundant c g requires empirical investigation if observer performance is to be optimized. advantage of minimizing uncertainty with complete redundancy must be comp d with the greater number of otherwise unique symbols that can be categorized via partially redundant coding. However, in both cases, a general conclusion that can be drawn is that no reduction in the number of steps within each dimension is required when these multidimensional combinations are used in symbology design.

Nonredundant coding. The symbology designer must be especially cautious in combining dimensions nonredundantly. In reviewing research prior to 1956, Miller (1956) noted that all studies found less than optimal information transmission via each separate dimension when dimensions were combined nonredundantly. That is, experimental subjects in the studies reviewed by Miller (Beebe-Center, Rogers, & O'Connel, 1955; Halsey & Chapanis, 1954; Klemmer & Frick, 1953; Pollack, 1952; Pollack & Ficks, 1954) were less accurate in identifying each unidimensional level of a multidimensional symbol than they were at identifying the same levels in unidimensional symbols. However, in all of the studies reviewed by Miller, increasing the number of dimensions resulted in an overall increase in the amount of information transmitted, or number of different messages identified. So, nonredundant combination of codes is a valuable approach towards symbology design. However, it would be useful to have some guideline for the degree of reduction in coding levels that can be accurately identified when dimensions are combined nonredundantly.

Miller (1956) has made the general conclusion that as the number of variables (dimensions and their corresponding levels) in a symbology system are increased, an increase in information transmission is coupled with a decrease in the accuracy of judgment for any particular variable. Although supporting research is lacking, it is probably accurate to make the related conclusion that as the number of dimensions combined nonredundantly is increased, the number of levels that can be accurately identified within each dimension decreases. Any more specific conclusion of this type is not supported by laboratory research. Additionally, the applicability of any more specific conclusion to an operational setting would be highly suspect. Thus, it is suggested that empirical research in the operational setting be conducted when nonredundant coding is used in an attempt to maximize the number of messages that can be coded.

SUMMARY

In this section, basic approaches to combining coding dimensions have been evaluated. It was noted that earlier discussions concerning the compatibility of dimensions with scaling categories and the value of dimensions in aiding search are still applicable in the case of multidimensional systems. The primary topic of this section has been the result of different combinations of dimensions on the number of messages that can be coded by a symbology system. Thus, multidimensional symbol identification was the major behavioral criteria of interest. The important interrelationships between identification accuracy within each level, number of different messages that could be identified, and type of combination used have been discussed. The following generalizations were made:

- As the number of dimensions combined redundantly is increased (up to some optimal number), levels of dimensions are more accurately identified, but the potential for information transmission is reduced.
- As the number of dimensions combined nonredundantly is increased (up to some optimal number), levels of dimensions are less accurately identified, but the potential for information transmission is increased.
- When partial redundancy is used in combining dimensions, search is aided, identification of levels is moderately improved, and the potential for information transmission is moderately reduced.

SECTION 14

A MODEL FOR THE DEVELOPMENT OF SYMBOLOGY SYSTEMS

The preceding sections of this report have presented a great deal of data on a large number of factors related to the development of effective symbology systems. Because each section is in itself a review and summary of current knowledge of these factors, no additional summarization is attempted in this section. Instead, this section presents a detailed diagrammatic model of the relationships between the many factors and symbology system characteristics described in the preceding sections. The model depicts many of the critical factors that must be considered in the development of effective symbol systems, and indicates the logical relationships among these factors. It is not, however, intended to provide a simple step-by-step procedure for selecting a symbology system. The model is shown in Figure 36, a foldout page at the end of this section.

The upper portion of the model indicates the necessity of considering the full range of tasks to be performed that involve the use of the symbology system. From this task set, all of the information requirements of the final symbology system may be determined. Determining all information requirements influences the final selection of a symbology system in two major ways. First, it influences the selection of specific dimensions required to meet this requirement. Second, it determines the total number of messages that must be incorporated in the final symbology system.

Specific tasks and their associated information requirements can also be derived from the set of all topographic tasks. Definition of specific tasks will result in the determination of appropriate map scale, and the importance of rapid visual search associated with each task. Definition of a specific information requirement and a map scale will yield the appropriate symbol type—point, line, or area—which will depend upon map scale for some types of information. Definition of the specific information requirement will also result in identification of the scaling category required (nominal, ordinal, or interval) and the number of scale divisions necessary for meeting the level of precision in data display desired.

The selection of coding dimensions requires consideration of several important factors. Certain coding dimensions, such as color and size, are much better suited than others in aiding visual search. The required scaling category and number of scale divisions also tend to suggest the use of certain coding dimensions. For example, not all dimensions are compatible with the ordinal category of scaling and those that are compatible vary in the number of coding steps that can accurately identified.

There are also four other factors, not discussed in depth in this report, that influence the selection of coding dimensions. The first is that of "association value,"—the ability of a symbol to evoke an immediate and correct response of the object it represents. Symbols coded via different coding dimensions are known to be associated to a greater or lesser degree with specific information items. For example, color coding is commonly associated with general characteristics of terrain in topographic maps. The other three factors influencing the selection of coding dimensions have been collectively referred to as "operational factors" in this report—display characteristics, human perceptual capabilities, and the environment. The single or combined effects of these three factors influence the selection of certain coding dimensions in a symbology system. For example, high ambient illumination, low display dynamic range, and limited sensitivity of the human eye might preclude the effective use of brightness coding.

The set of all information requirements and the applicability of separate coding dimensions in meeting these requirements are the primary determinants of the number of coding dimensions used in a symbology system. Given the set of selected dimensions, the compatibility between these dimensions will suggest ways in which they may be combined. For example, it was suggested in Section 13 that inclination coding should not be combined with alphanumeric coding, but that both of these coding dimensions were compatible with color coding. When single coding dimensions are specified in conjunction with a symbol type, the unidimensional coding methods that are to be used in a symbology system can be determined. When combinations of coding dimensions and symbol types are specified, the multidimensional coding methods are determined.

The search requirements of a symbology system directly influence decisions concerning the use of coding redundancy. Information with a high search requirement is likely to to be coded using some redundant, rather than nonredundant, combination of dimensions. The type of coding redundancy and the number of coding steps within each coding dimension used for multidimensional coding determine the identifiable levels of multidimensional symbols. As noted in Section 13, the use of nonredundant coding will often require a reduction in the number of steps used with each dimension, as compared to totally redundant or unidimensional coding.

The number of possible messages that can be coded by the selected methods of coding is determined by the number of coding dimensions selected and the number of coding steps within each dimension for symbols coded unidimensionally. For multidimensional symbols, the types of coding redundancy and the identifiable levels of multidimensional symbols must also be considered in determining the number of possible messages.

During the process of selecting a symbology system, it is necessary to match the number of possible messages to the number of messages required, using the most effective coding methods possible. The selected symbology system identifies the coding methods, coding dimensions, combinations of dimensions, and redundancy patterns to be used in symbolizing the required messages. Selection of a symbology system does not, however, complete the task of the designer. It is still necessary to design or select specific symbol sets, such as specific pictographs for shape coded point symbols. This final selection process must result in a symbol set that is compatible with the organization of the selected symbology system, and is strongly influenced by the association values and the operational factors previously discussed.

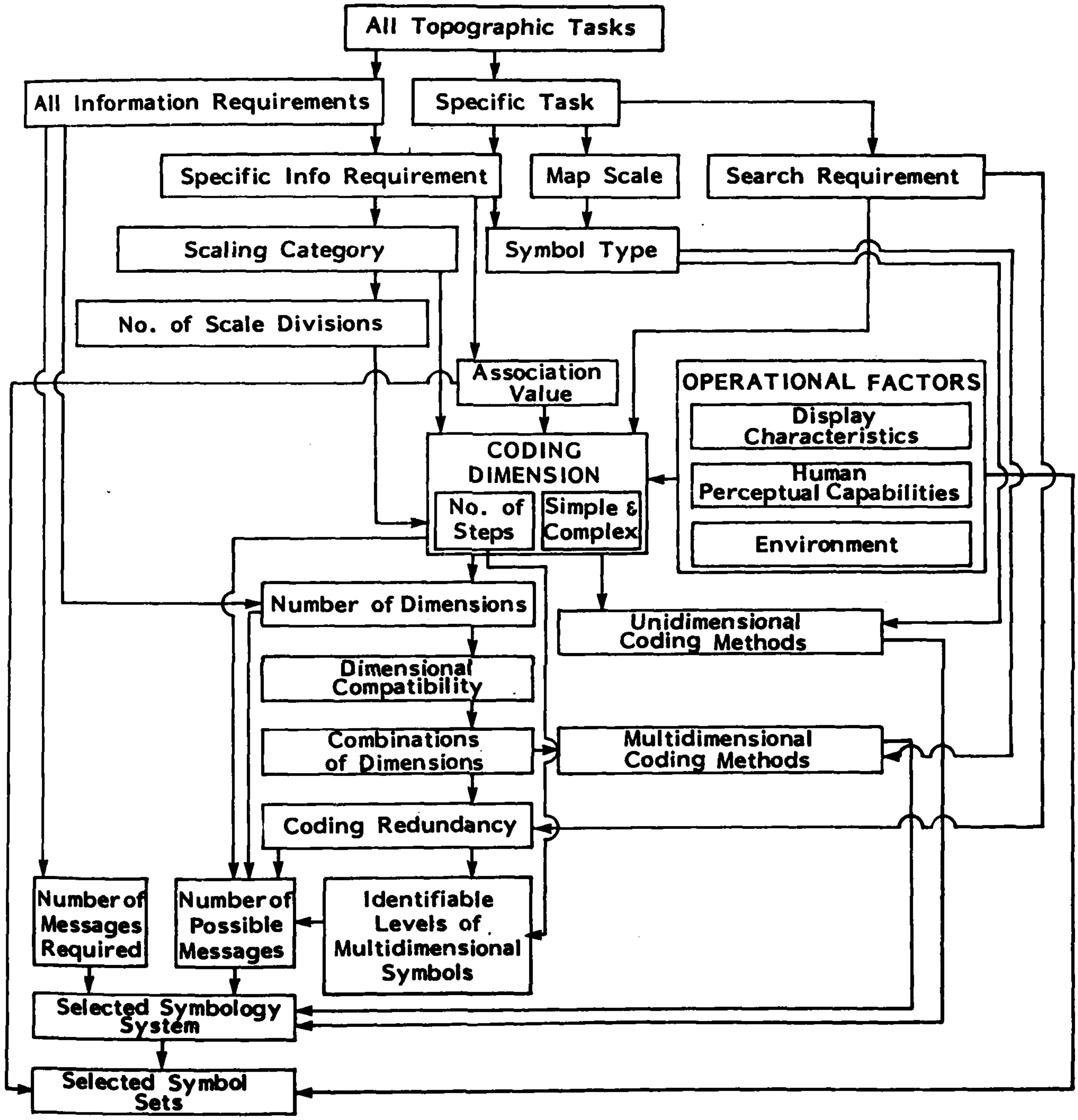

Figure 38. A detailed model of many critical factors that must be considered in the development of an effective symbology system.

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